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National Power Grid in China: the reform of electricity industry

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Abstract

Separation of transmission and distribution is the core for the new reform of electricity industry in China. To solve problem with long distance transmission, the two national power grids started Ultra-High-Voltage (UHV) transmission lines in 2006. After July 8th 2010, UHV lines started to operate. In March 2015, Document No.9 issued, to deepen the reform of electricity sector by separating transmission and distribution, and privatizing retailing. This paper will focus on the change in economic scale after separation by empirical analysis, and which pricing mechanism to choose.

Keywords

Energy economy, economies of scale, natural monopoly, monopolistic pricing, privatization

Range of thesis: [87 Pages, 13082 Words]

Declaration of Authorship

1. The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

2. The author hereby declares that all the sources and literature used have been properly cited.

3. The author hereby declares that the thesis has not been used to obtain a different or the same degree.

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Proposed Topic:

National Power Grid in China: the reform of electricity industry

Registered in SIS: Yes **Date of registration: 29/05/2014**

Topic Characteristics:

My thesis will focus on governmental incentives for reform in the energy industry corresponding the institutional reform undertaking by the Chinese government. China's energy profile provides a window into its economic soul. (Rosen 2007) The function of analysis of the energy sector is to analyze the reform process and features of the energy market in China". There will be 4 major points discussed. First, briefly trace the history of development of electricity sector of China; second, how the power grids formed, include the patter of the reform process. Third, detailed analysis how the power grids acts in China, if they are efficient. Forth, focusing on the institutional regulation, their function, the legal process, and the transparency.

Literature Review

Today China's share of global energy use has swelled to over 15 percent and the country has been forced to rely on international markets for more of the oil, gas, and coal it consumes. (BP 2006) Heavy industry is the driven force that increase the demand of energy in China. China's energy system is increasingly unsuited to manage demand in a secure manner, and for the medium-term Beijing and other countries will need to work around that system with second-best solution. (Rosen 2007). The problem with

China's energy profile is domestic. China's energy challenge is rooted in systemic conditions that go beyond the energy sector, so the policy alone will not provide the solution. It needs the comprehensive change.

Hypotheses:

1. Auction transparency is necessary but not approachable inside the environment of Chinese politic.

2. Fixed price system will not be challenged by the new round of reform.

3. Ex-ante policies are more necessary than ex-post policies.

4. It is necessary to keep the Power Grid state-owned.

Methodology:

Detail analysis of state operations will start with an analysis of an official document.

Direct observation from the local power plant in China, to gather accurate information about how a program actually operates, particularly about processes, study in their bidding process and interview some of the authorities in the industry.

Interview the employer and employees in person, fully understand their impression about the sector. Case study about the failure in integrity of the regulation.

Outline:

1. Introduction
2. Theoretical background and the literature review of the academic opinion about reform process undertaken by the Chinese government
3. The Route of Development of Energy Sector in China
    a. 1985-1996 Industrial decentralization
    b. 1997-2001 National discussion of power sector reform swept the country following a brief power surplus
    c. 2002-Now Market oriented reform
4. Institutional Analysis
    a. Regulatory authorities and to what extend they are sufficient or efficient
    b. Price control and pricing related to the government intervention
    c. Auction transparency and institutional regulation

5. Conclusions and Recommendations

6. References / Bibliography

1. Xu, Shaofeng, and Wenying Chen. 2004. "The Reform of Electricity Power Sector in the PR of China." Energy Policy 34, no. 16 (2006): 2455-465. doi:10.1016/j.enpol.2004.08.040.

2. OECD. 2009. “Reviews of Regulatory Reform China 2009 Defining the Boundary between the Market and the State.” Paris: Organization for Economic Co-operation and Development, 2009.

3. OECD. 2006. “China's power sector reforms where to next?.” Paris: International Energy Agency, 2006.

4. White Paper: China's Energy Policy 2012, by State Council of the People's Republic of China "Far East Energy Welcomes China's Gas Pricing Reform." Worldwide Energy , August 1, 2013.

Author Supervisor *

Contents

Introduction:

According to Adam Smith (1784), the most powerful instrument in market economy is the invisible hand, which automatically adjusts the market to its equilibrium[1]. What if the economy is under government planning? Buchanan (1982) stated that there does not exist an omniscient designer who knows the utility functions of the whole economy. Hence, in a planned economy, the suppliers and consumers will not find each other at the price equilibrium, and the pre-determined price will be either over- or under-estimated by the designer. According to Stiglitz 1988, such market inequilibrium will generate dead weight loss, causing a decrease of overall social welfare.

The energy sector is one of the most important primary industries in an economy. A slight price change may turn into a prominent influence in many other industries. Having an efficient energy industry is crucial to keeping a nation competitive in the world.

Due to the fact that the energy sector has been centrally planned in China over a long period of time, and its relevant institutions and regulations are incomplete, the retail price of electricity has never met its market equilibrium, causing an increase in cost for many companies. While China's manufacturing industry has been losing its competitiveness in the global market, the electricity price has continued to increase.

[1] Invisible hand may not exist in transmission and distribution part, but in many countries it does exist in retailing part.

This is detrimental to both the manufacturing industry and the attempt (by the government) at economic transformation.

To combat these issues, the Chinese government made its decision in March 2015 to reform electricity by separating transmission from distribution and retailing, and encourage market competition in retailing by releasing Document No. 9, “Further Strengthening the Institutional Reform of the Electric Power Industry”.

There has long been debate over marketizing energy. Traditionalist views that believe power grids to be a type of public goods have been stopping the electric sector from further development. (Wang, 2010) The arguments for such views involved issues of national security, economies of scale, and technology. Since power grids are responsible for electricity transmission and needs to be reliable and consistent, they should be under government control. Also there are barriers for private sectors to entry. The fixed cost of transmission line construction is too expensive for private firms (Delmon, 2009). Power grids follows natural monopoly characteristics, so less competition will introduce additional benefits of the economy of scale. Besides, most of the private firms are not authorized to use many of the technologies.

With consideration for these arguments, the Reform states that existing power grids which are state-owned enterprises, are responsible for and only for electricity transmission. Distribution will be taken over by regional and provincial power grids, and qualified private entities (details in Chapter 5) will be allowed to enter electricity retailing.

The Reform will also change the power generation sector. Currently, power plants are located dispersively, causing widespread pollution that is more difficult to manage. Compare to large, concentrated power plants, dispersively located plants cause the difficulties to pollution control. Most of them are coal-firing thermal-based power plants may not follow the regulation of emissions, thus having each of the power plants supervised is quite difficult. In 2014, coal-fired generation capacity approached 800 million kilowatts, accounting for approximately 78% of country's total electricity generating capacity. (NSD, 2014) This causes massive environmental problems, including large amounts of carbon dioxide and nitrogen oxide emissions. In 2012, China accounted for 20% of global energy consumption and more than 20% of carbon dioxide emission. (LNBL, 2014) According to an air quality report from 2010 to 2014, Beijing was measured as severely polluted during 22% of the time. (Stat PKU, 2015)[3] Appendix A 1 is a real time air pollution map from the Air Quality Index Organization on May 10th, 2015 displaying the pollution levels in Chinese cities. Severe pollution is labeled red.

To protect the environment and accomplish the 2030 standard[4],China has been actively expanding its clean energy sector. In 2013, China's overall installed electric

[3] Severe pollution means PM 2.5 reached 150 mcg/m^3

[4] The State Council of People's Republic of China released news press in March, 2016, proising in 2030 the CO_2 emission will hit a peak. It is a single standard regulation on CO_2 emission

generating capacity increased by 8%, and with around 12% of it in clean energy. (IRENA, 2014) According to Appendix A 2 which shows the cumulative renewable power plant capacity in China, hydro power plants have seen the largest increase among all clean energy in the past few years, but recently wind and solar power plants have begun to increase gradually. The provinces of Qinghai, Xinjiang, Tibet, Inner Mongolia, Sichuan and Gansu account for the largest share of installed solar photovoltaics (PV) capacities, while they represent more than two thirds of the national solar energy resource potential (CNREC, 2013a). Wind parks are mostly located in North China (CNREC,2013a), while hydro energy is concentrated in the Hubei, Sichuan, Yunan, and Tibet provinces. One third of the power plants are small-scale hydro and supplies a quarter of the population, while major hydro plants and developers are state-owned.

Hydro and wind energy are both highly reliant on geographical conditions, so it is optimal to build large, concentrated generation centers within an area rich in resources, and transmit electricity via transmission lines to other regions. For example, Inner Mongolia is a province rich in wind resource with an installed capacity of 18,330 megawatts (MW), and Beijing is a load center. Ideally, the wind park should be built in Inner Mongolia, and electricity will be transmitted to Beijing for consumption.

Inconsistency of energy generation is another reason to build long-distance transmission lines. Both daily and seasonal outputs of large power plants will vary.

For example, the daily output of a 33 * 1500KV wind farm will vary between 33 and 45%, and its seasonal output between 20 and 57%. (Fan et al., 2012) Appendix A 3 shows the range of its daily output as between 1,824-34,155 KW in spring, 0-34,155 KW in summer, 11,513-32,742 KW in autumn, and 10,099-34,115 KW in winter (NDRC-JP, 2015). Daily output varies greatly in different seasons.

Security of supply is another factor in the electricity industry. One of the biggest difficulties in managing renewable green power is the inability to store large quantities of electricity for future use. If the output level of a wind park changes greatly, its consumers must have easy access to other electricity suppliers from other regions. For this purpose, long distance, low-line-loss transmission lines are required. Further, institutional barriers have to be removed to create better inter-connection among different networks.

In 2009, the 1000KV Jindongnan-Nanyang-Jingmen UHV Alternating Current (AC) transmission line, the first of such UHV lines, has passed its tests. It started operations on July 8th, 2010. As of 2014, 20,881[5] km of UHV transmission lines has been put into operation. There are several advantages UHV technology. First, it has a large capacity -- the overall installed capacity, in 2014, is 155,800 KW[6]. Second, it performs well over very long distances - the Jindongnan-Nanyang-Jingmen UHV AC line is 640km long, and theoretically, UHV transmission can function properly up to a

[5] Calculation based on Suo, 2016
[6] Calculation based on Suo, 2016

distance of 2500km. Third, it has a relatively low line loss-- its line loss is only 60% of that of 600KV transmission lines over comparable distances.

These advances in technology has enabled a reliable and sustainable method of long distance power transmission within the nation. The remaining problem is the institutional structure. Under the current power grid management system, the transaction cost of inter-regional transmission is relatively high. According to SDPC (2009), inter-regional prices are dictated by delivery prices, transmission prices, and line loss. Hypothetically, the model constructed in this paper will assume that the two power grids are operating at the national level as transmission companies without transaction cost in between the two.

This paper will focus on estimating the cost of separating distribution and transmission sector by using ordinary least square regression following the adjusted model originated from Zhang et al. (2010) and to observe the change of economies of scale in both transmission and distribution sectors with and without fixed cost. Economies of scale may increase after separation according to Edwards and Starr (1987). Mansfield (1976) stated a valid point that some of the inputs are not available in smaller parts, thus indivisibility may increase fixed cost after specialization.

After estimation, we will try to find a theoretical pricing mechanism under the Reform for transmission companies to prevent monopolistic inefficiency. We will also discuss the necessities of entry barriers in electricity retailing, and how these barriers might affect the reform process. Starting from the establishment of the current government, reform in the electricity industry has never stopped, but none of them has led to a free electricity trading market. Separation of transmission is at the core of the Reform, and will change the current electricity industry significantly.

1. History of Reform

1.1 1949-1985

This was the time period when power industry was a state monopoly; the function of government and business was unified. The government acted as sector managers, producers, operators; they were also responsible to enforce laws. The assets of the business were also counted as state property. The administrative agencies of the State Council were not only responsible for policy but also for execution. Those agencies who were responsible for almost all the business of the firm were also investing into the firms and obtaining earnings from their invested projects.

The structure of regional power industry is fairly similar to the central one, also with combined function of government and business entities. The only major difference was that their decision making was under control, and was supervised by the higher level administrators. Since the demand and supply of electricity was central planned, the electricity enterprises were responsible to adjust the supply of electricity according to the previous months. The difference of adjusting process between private and state-owned enterprises was the speed of reaction. Usually for private firms the time period was shorter, because they did not have to go through strict censorship. However, the vagueness between government and enterprise had encountered several severe problems such as the constriction of industrial development, and discourage of investment.

1.2 1985-1997

The reform carried out in 1985 allowed investment by third parties including regional government, and some domestic and foreign private investment. Power plants built and purchased by these investors are now account for over half of total capacity (IEA, 2006). Even though these power plants were regarded as owned by independent individuals, their shares were purchased by the regional government or other entities related to central government officials. During this period we could still regard the power industry was solely owned by the government.

Until 1985, China's power industry was fully under the control and owned central government. After introducing the liberalizing policy towards encouraging third parties' investment, the industry and installed capacity were expanded. The new policy led to the further investment at the local level, and this increase of investment lasted until the mid-1990s. Investment coming from local level was only counted around 14% of the total industry and increased to around 40% in 1995[7]. After 1995 private investment declined mainly because the increasing cost of investment in energy sectors. In another word, the installation cost of energy sector was too high for third parties to invest.

In 1993, China invited The World Bank to consult on their reform on power sector. The World Bank suggested China the separation of power sector from the government

[7] IEA, 2016

and to commercialize the industry. The advice given by The World Bank led to more foreign investment towards different parts in the industry and higher consumption.

However, institutionally, there were not many changes compared to the period before 1985. The power sector was equipped with a set of ministries or very large state-owned enterprises. They were responsible for sending reports to State Planning Commission and the State Economic and Trade Commission including their asset management, investment, panning, and price regulation. The State Planning Commission was responsible for verifying all major investments and all energy prices.

1.3 1998-2002

Starting from the second half of 1997, another round of reform was being implemented. The Ministry of Power Industry was in charge of this operation, transferring nearly 40% of the installed capacity to the newly formed State Power Corporation. [8]This was the first step separating market enterprises from the government administration. The government role was shifted to a new administrative entity called State Development Planning Commission. At the same time, the former Ministry of Electric Power was dismissed, and its assets has been transferred to the new State Power Corporation.

[8] 国家电力公司

After the fatigue of third party investment[9], government has introduced several stimulus policies, encourage foreign investments. New plants was allowed to charge higher prices to cover their costs and to maintain a fixed return on profit. Initially, those new plants in between 1986 and 1992 did not require central governmental funds. After 1992, the newly built plants were allowed to charge higher price regardless of the types of ownership. The new price was set differently by the government. Government started to form complete price regulations. Transportation cost and electricity pricing was combined to form a unified price. Individualized pricing transformed to average social cost mechanism.

1.4 2002-2013

In December 2002, State Power Corporation broke down to 2 power grids[10], 5 large generation companies[11], and 4 auxiliary service companies.[12] The document No. 5, *"Implementation of Power Sector Reform"* has been introduced in February. The State Council established the State Electricity Regulation Commission (SERC). SERC is responsible for regulating the power sector from a standardized administrative system, proposing institutions, and regulating competitions. SECR issued the decrees to set up the first competitive energy market in northeast and east China. The State

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[9] When third party starting to have less profit, they were tired of continuing to invest.

[10] State Grid Corporation of China and China Southern Grid (SGCC)国家电网公司, and China Southern Power Grid Company (CSG)中国南方电网

[11] China Huaneng Group (CHNG)中国华能集团公司, China Guodian Corporation (GUODIAN)中国国电集团公司, State Power Investment Corporation (SPIC)中国电力投资集团, China Huadian Corporation (HUADIAN)中国华能集团公司, and China Datang Corporation (CDT)中国大唐集团公司

[12] SDIC Power Holdings Co.,Ltd. (SDIC)国家开发投资公司电力有限责任公司, Guohua Electricity Power Corporation(GHEPC)神华北京国华电力有限责任公司, China Resources Power Holdings Company Limited (CRP), 华润电力有限公司 and China General Nuclear Power Group (CGNPC)中国广核集团有限公司

Council issued the “Scheme of Electricity Tariff Reform” to help with developing an efficient pricing system by classifying on-grid, transmission, distribution, and retailing tariffs.

Document No. 5 has certained the direction of reform. It separated electricity industry into two sectors : the power plants and power grids. Power plants was only responsible for power generation. Power grids were responsible for transmission, distribution, and retailing. Market competition was introduced in generation part, but there were only two buyers. Thus, Document No. 5 did not introduce a competitive power generation market, but it formed a power generation market led by state-owned enterprises. (Feng, 2015) Power grids grew faster and became profitable enterprises.

2. Technical Barriers

2.1 Technological Barriers

2.1.1 UHV

Transmission system is the system transporting electricity from the location of its production (power plants) to the sub-stations. Generally, high-voltage (HV) three-phases alternating current (AC) is used in electricity transmission, but in rare case such as railway electrification systems, single-phase AC might be used. In China, there are three standards of transmissions: ultra-high voltage (UHV) from 1000KV and above, extra-high voltage (EHV) in 330KV, 500KV and 750KV, and high-voltage (HV) from 110KV to220KV. The standard may vary through the development and expansion of the entire transmission system degrading the transmission lines into distribution lines.

The major function of the transmission line is to deliver bulk electricity in a secure and efficient manner. In the modern electricity system, power plants are located far from its users. The power plants would prefer to sell their electricity at its closest transmission sub-station, while the users would like to buy the electricity at the closest retailing point. In China, most of the resources are located in the northwest region, and the end users are condensed along the eastern and southern coasts. For about 60 years, transporting the primary resource is preferred by the power plants since the loss of energy is smaller, which could help the power plants achieve a lower cost of production; however, with the fast development of UHV technology in China, transmitting electricity via UHV lines may be more efficient.

According to the resource distribution, the Chinese government decided to build long-distance, large capacity and low line loss transmission lines to achieve transmission from large generation centers to load centers, and to have the electricity network interconnected at the national level. The UHV 1000 KV alternating current (AC) and UHV 800 KV direct current (DC) standards were chosen. At the beginning, the electricity is transmitted by using differentiated voltage. This can lower systematic loss.

Due to the distance of transmission, power of UHV transmission can reach 5000 MW. Since the cost of a UHV transforming power station is fairly high, differentiated voltage transmission is quite practical and economical. Operation of UHV lines are limited by altitude, weather, manufacturing standard, sustainability, and the quality of circuit breakers. Different qualities of insulators are required based on the altitude of a hydro power plant. Weather can cause the corona effect and lead to an increase in line loss. Current manufacturing techniques for circuit breakers limit its effective protection at below 1100KV. Hence, a UHV 1000 KV transmission line might be chosen at 1050 KV or 1100 KV. According to the statistic data in 2010, the net loss from 1050 KV and 1100 KV is 1.66 and 1.64 respectively. (Zhang et al., 2010). Real voltage for 1050 KV is between 996.6-1041.3 KV and for 1100KV is around 1021.7-1080 KV.

Under severe weather conditions, corona will appear and the net loss of UHV transmission lines will increase. At 1050 KV, total net loss with corona will increase by 1243 MW and for 1100 KV 1489 MW. Rate of net loss for 220 KV and above increase by around 0.38% (Zhang et al., 2010). Geographically, transformer stations will not be located over 1000 meters high; however, the transmitting corridor may be located over 1000 meters. Level of insulation needs to increase with higher altitude. At an altitude of 2000 meters, a 1050 KV line would require insulation suitable for a sea-level 1167 KV line.

The stability of UHV technology has passed several tests[13] and several transmission lines have been tested. The results have been satisfying. For instance, ChuanYu - Hua Zhong transient stability has increased between 89.6-129.4 MW (1.82%-3.24%) at 1100 KV compare to that of 1050 KV. At manufacturing barriers, even though its limit of operation has not been tested, and other related equipment also need to solve its technical issues. Reference price for every kilometer UHV 1100KV transmission lines is 4.5-6.5 million RMB. 1050 KV is only around 0.1-0.7 less. (Zhang et al., 2010) It is affordable to build UHV 1100 KV transmission lines. From the information we have, it is reasonable to have UHV transmission lines in commercial use, and have them wide-spread over the nation.

[13] Tests has involved test of line loss, test of security, and test of consistency. (2014)

2.1.2 Smart Grid

Smart grid is the grid embedded with large data processing abilities, notifying the supply and demand from power plants, power grids and end users, and adjusting the supply and demand based on its individual needs. Smart grids can have continuous self-evaluation, and self-detection. It can realize its problems and bugs by itself, and make adjustment to errors. (The Climate Group, 2011) To avoid the potential risk of electricity shortage of UHV transmission lines, it is better to equip smart grids together with UHV.

Smart grid has first experimented in Italy in 2001, the companies has started (Automated Meter Management (AMM) project, it helped to decrease peak load by more than 2.5, and saved around 500 million operational cost. (IBM, 2006) IBM has proposed Solution Architecture for Energy (SAFE), this has a high possibility to self-maintenance of smart grids. Appendix A 7 shows the process of SAFE by IBM.

Smart grid has been part of the national strategic plan for increasing power efficiency. In north, northeast, and northwest China, 22-23% of wind energy was wasted in 2012, and around 12% in 2013 (Zhang, 2014). In some solar PV plants, there was also energy waste but without precise statistical data (Wang, 2014). The reason for energy waste is first, energy is a real-time asset. There is difficulty in storage. Second, the instability of wind and solar energy generation may cause inefficiency. We can observe the fluctuation.[14] To avoid energy waste and to lower cost, having smart grid may be a appropriate option.

2.2 Political Barriers

2.2.1 Power Grid Levels

There are 2 national level power grid companies: SGCC and CSG. Due to Chinese geographical latitude, SGCC and CSG are divided into 6 regional power grids. The Northeast Power Grid, North China Power Grid, Central China Power Grid, East China Power Grid, the Northwest Power Grid belongs to the SGCC, China Southern Power Grid belong to CSG. Large regional power grids are for easier management purposes.[15]

Next level of management is provincial and city power grids[16]. For Central China Power Grid, it consists of six different provincial power grids. In which, Henan Power Grid is connected to Northwest Power grid, and Hubei Power Grid is connected to East China Power Grid. Provincial power grids are consist of city power grids. For examples, Shanxi Power Grid[17] is consist of 11 city power grid. City power grid is responsible for distributing power to lower grid level and to some large end users. Basically, for city power distribution network, there will be three or four 550[18] KV

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[14] Appendix A 4 shows the fluctuation of daily generation change within a year. Appendix A 5 illustrates power generation within a randomly selected continuous 15 days. Appendix A 6 shows curves of power generation in two typical adjacent days. We can observe the fluctuation.

[15] Apppendix A 8 is an illustration of regional power grids in China

[16] Appendix A 9 illustrate how provincial and city grids are interconnected

[17] Appendix A 10 illustrates Shanx Power Grid

[18] Level of power grids is similar to Germany

transmission line for communication purpose (normally connected to provincial power grids) and the rest are 220 KV and 110 KV loop lines. There are exceptions when the regarding some large industrial parks may have their own distribution network and the level of voltage may be higher than the city level.

2.2.2 Trading Barriers

With different grid level, there are trading barriers. Price of inter-provincial and inter-regional grids are different from price of trade within. The difference in price has been a difficulty to have cheaper electricity from other places[19]. On- grid price is set differently in each province. Appendix B 1 is a chart of on grid price in different provinces in China. We can tell it vary greatly. In some of the provinces, it can be as low as 0.033 RMB/KWH, but in some provinces it can be as high as 0.045 RMB/KWH. The inter-regional and inter-provincial on-grid price is negotiated bilaterally. The price can vary with different contracts. [20] The existing barriers of trade is not beneficial for smart grid to achieve its goal that have efficient resource allocation. Transaction cost may prevent efficiency of resource allocation.

[19] SDPC, 2015. 发改价格[2015]3105 号
[20] SDPC, 2015. 发改价格[2015]962 号

3. Estimation of Distribution and Transmission Separation

3.1 Motivation of Research

Power grids and transmission lines are physical assets. Their functions are carried out by the enterprises and government under related institutions and regulations. Analyzing separation of transmission and distributions lines we have to first clarify the separation functions of transmission lines and distributions lines under UHV and smart grid.

Transmission lines are the transportation system of electricity at the national level. They are responsible for long distance bulk transmission. While the reliability of electricity supply has been a discussion, it is better to have the transmission companies remain state-owned. Distribution companies can be the previous regional and provincial transmission companies, and retail can be carried by both state-owned companies and private companies. The natural monopoly characteristic of transmission lines leads to difficulties in competition. The large fixed cost and installment has created a barrier of entry for private companies.

According to transaction cost economics (TCE), if a well there is a well-formed management system combined transmission and distribution together, then there will be even less transaction cost compare to separation. [21] Under different economies, the situation differs. As for China, under current situation, the conflict between future

[21] Less transactions are made within the combined system, according to TCE, less transaction will lead to lower cost.

plan and current situation is crucial. Smart grid and UHV may not have its optimal outcome under the current political and systematic barriers. The United Kingdom has reformed its electricity sector by privatization and separation of transmission and distribution. In the United States, the electric properties are owned by different entities, there are public sectors and private sectors. Generally, the function of transmission and distribution has been separated, but the ownership of property still remains complicated.

There is not evident conflict to have transmission and distribution within the same enterprise, but the decision to separation should be made by evaluating the institutional history. (Hunt and Shuttleworth, 1996) The separation has to be considered with the general development of economy. If the timing of reform is not appropriate, there will be large force to prevent the reform from happening. As an example of the U.S., formulating independent transmission companies had encountered severe resistance (Hunt, 2002).

Reform has to consider the cost and risk of changes. Transforming from the current system to the new one may increase the overall cost of society. Generally, the wider[22] the reform, the higher the risk. Some technological separation of distribution and transmission may lower the efficiency of operation, and raise the risk of sustainability of electricity supply. Repetition of institutional sectors may also generate extra cost

[22] Refers geographically.

for the entire economy. Under the combine transmission and distribution, they have shared technology and shared institutional entities. These features may had lowered the retail price of electricity.

With the separation, there might be conflict between interest groups. For example, privatizing the retail section may affect the existing profit of power grids. The conflict between interest groups should be solved before the execution of reform. Thus, negotiation among interest group is essential. The cost of negotiations is difficult to measure, but it may also increase the overall cost of separation.

Under combined transmission and distribution, power plants only face two buyers, theoretically. The current competition in China has concentrated at the side of power generation, but not power grids. This fact also follows Hunt's (1996) theory. Under one side competition, investors should gain their right to invest by auction, to have the most competitive price. Auction theory suggests, efficient institutional design can help to form competitive price, in another word, the process of auction and function as a competitive market (Klemperer, 2004) However, compare with auction, designing an institution to separate transmission and distribution may be easier for the government.

3.2 Literature Review

Power transmission lines provide an excellent example for economies of scale. For every extra unit of electricity transmitted, the cost per unit of electricity will decrease.

According to Finite Population Correction statistics, prominent economies of scale could be found in the study of the average cost function of point-to-point transmission; (Weiss, 1975) however, no specific functions were given. Scherer (1976) has formulated a total cost function for single point-to-point transmission lines. He first assumed that there is no operating cost in the distribution network, only capital and maintenance costs, and then calculated that the total cost of electricity transmission could be expressed using fixed cost plus the average of marginal cost.

Jowkow and Schmalensee (1983) pointed out that the economies of scale of the electricity line is related to point-to-point transmission lines and the utilization of multiple loops. According to the basic principles of power systems, transmission line loss is approximately inversely proportional to the square of the voltage, i.e. the higher the voltage the smaller the line loss. With increasing transmission capacity and voltage level rises, the average cost of a unit of electricity transmission will decrease because of the reduced line losses. At the same time, this also explains why the transmission grid uses high voltage levels. Grid construction needs to occupy large areas of land and the construction of a number of facilities and equipment installations, resulting in higher fixed costs of investment in the transmission grid.

According to Tirole (1988), the fixed cost is a special case of economies of scale. At a given level of investment in fixed costs, the greater the decline in the average cost of a range, the more obvious economies of scale. Thus, higher fixed costs of the grid shows that it has significant economies of scale. Grid investment has inseparability (lumpiness), according to the power system theory and practical experiences. For countries that are constructing higher-level grids, the general level of the adjacent voltage ratio (high/low) is set to 2, so that transmission capacity will grow to four times the original, and the original investment is no more than twice. Therefore, with the increase of transmission capacity, the average of the final cost will be lower than the minimum average cost under the original voltage level. For example, double-circuit transmission capacity is generally twice of that of a single-loop, and the construction cost is much lower than double the single-loop, so average of the final cost will be lower than the average single-loop.

Baldick and Kahn (1993) depicts two possible economies of scale and the investment performance of the inseparability (lumpiness) transmission cost curve after considering a variety of transmission costs, and noted that the cost of transmission network displays significant economies of scale.

The horizontal axis represents transmission capacity, transmission distance and the vertical axis represents the unit cost. (Appendix B 2) Suppose two voltage levels are 115 KV and 220 KV, are set to take double loop, a single line transmission limit the voltage level at respectively 125 MW and 500 MW. When a single 115KV transmission line cannot meet the requirements, the second line will be put into use, when the voltage level of 115 KV transmission cannot meet the requirements, 220 KV level will be put into use. Scherer curve (Appendix B 3)and the curve is similar to Appendix B 2. Shaded slope shows the average cost of transmission. Low cost curve transmitted the envelope curve is given, it can be seen from the envelope curve, Baldick-Kahn curve is a curve Scherer extended and deepened.

3.3 Hypothesis and Cost Function

Electricity industry has a significant economies of scale. After separation, the range of business is narrowed, hence there will possibly decrease in fixed cost. This decrease may apply to both transmission and distribution part. The economies of scale may be enlarged. There possibly will be economic loss generated from the separation, and it should be proportional to the total cost.

The choice of cost function is important. The formulation of cost function has to follow the 3 considerations. First, cost function should obey microeconomics theories. It should be non-negative, non-decreasing, concave, and include major factors of cost. Second, the function should be continuous and precise. Third, cost function should be suitable for ordinary least squares regression (OLS regression).

Considering the selected model and data, Zhang, et al. (2010) cost function may be optimal. It has been normalized using Martinez-Budira, Jara-Diaz and Real (2003) method. This quadratic cost function is not a standard quadratic cost function, but a compromise between standard quadratic function and transcendental logarithmic production function. Zhang, et al. (2010) separates the transmission and distribution network based on 220KV level, which is the separation between provincial and city level. Appendix D 1 illustrates their separation.

Zhang, et al. (2010) has its combined total cost function as:

$$C = \alpha_0 + (\beta_1 P_L + \beta_2 P_L + \beta_3 P_L) + (\gamma_1 R_1 + \gamma_2 R_2 + \gamma_3 R_3 + \gamma_4 R_4 + \gamma_5 Y_1 + \gamma_6 Y_2)$$

$$+ (\alpha_1 T + \alpha_2 D + \alpha_{11} T^2 + \alpha_{22} D^2 + \alpha_{12} TD)$$

$$+ (\beta_{11} TP_L + \beta_{12} TP_K + \beta_{13} TP_E + \beta_{21} DP_L + \beta_{22} DP_P + \beta_{23} DP_E)$$ [23]

(D4)

And ratio of loss can be measured by:

$$VE = (T, D; w) = [C (T, 0; w) + C (0, D; w) - C (T, D; w)] / [C (T, 0; w)]$$

Where $C (T, D; w) < C (T, 0; w) + C (0, D; w)$[24]

3.4 Data and Assumption

The data is from 2011-2014[25] SGCC and CSG. The reason to choose data from this time period is because from July 2010 the first UHV transmission line was put into operation. Even though there are only 8 observations[26], because we only want to estimate the cost of separation when SGCC and CGS are responsible for UHV transmission line at the national level, the regional and provincial data are not required[27].

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[23] The cost function has been standardized by Martinez-Budria et al. Method (2003) based on Ramsey pricing function. Ramsey pricing derivation see Appendix D 8

[24] C = C (y; w) stands for total cost of provincial companies, detailed explanation please see Appendix D

[25] The time period is so short because from July 8th 2010 the first UHV transmission line was put into operation, the data prior to the date does not exist.

[26] The 8 observations are composed by SGCC and CSG from 2011-2014, each has 4 observations. Limited amount of observations made our regression very similar to calibration.

[27] Zhang et al. (2010) had their separation at the provincial level, which they had the separation voltage of 200KV.

We have 8 observations with their data for total cost (TCOST), transmission output (TRANSOUT), distribution output (DISOUT), square of transmission output (TRANSOUT2), distribution output (DISOUT2), interaction of transmission output and distribution output (TRANSDISOUT), price of labor (PRICE_L), price of capital (PRICE_K), price of electricity (PRICE_E), product of transmission output and price of labor (TRPR_L), product of transmission and price of capital (TRPR_K), product of transmission and price of electricity (TRPR_E), product of distribution output and and price of labor (DISPR_L), product of distribution output and price of capital (DISPR_K), product of distribution output and price of electricity (DISPR_E). Total cost is the overall cost of the enterprise for the specific year. Transmission output is the potential output of the transmission lines (capacity). Distribution output is also the potential output of the distribution lines. Price of electricity is the price of on-grid electricity.[28]

Different from the original model, transmission line is defined as UHV transmission level with 800 KV and above. Distribution line is defined as HV transmission level with 500 KV and below. We assume transmission lines will be operated by SGCC and CSG at the national level, hence, regional and provincial power grids will not be involved in UHV transmission. Regional and provincial power grids with 500 KV transmission lines and lower will be degraded to distribution lines.

The illustration of their separation please see Appendix D 1.

[28] This is similar to Zhang et al. (2010) with first term, quadratic term, and interaction terms.

3.5 Method of Estimation

The model of estimation is as follows:[29]

$$TCOST = \beta_0 + \beta_1 TRANSOUT + \beta_2 DISOUT + \beta_3 TRANS2 + \beta_4 DISOUT2 + \beta_5 TRANSDIS + \beta_6 PRICE\_L + \beta_7 RPRICE\_K + \beta_8 PRICE\_E + \beta_9 TRPR\_L + \beta_{10} TRPR\_K + \beta_{11} TRPR\_E + \beta_{12} DISPR\_L + \beta_{13} DISPR\_K + \beta_{14} DISPR\_E + u \quad (1)$$

[30]

in D4[31]. According to its setting, total cost is explained by transmission output, distribution output, quadratic of transmission output, quadratic of distribution output, three factors of price, and cross products of three factors of price and transmission output and distribution output.

In the original model, Zhang et al. (2010) assumed there will be regional and time factor affect the model, because their model is based on separating transmission and distribution lines at the provincial level. Since our model will be estimating the separation at a national level, regional factors will be excluded from the disturbance.

Hence, disturbance could be explained as:

$u = \alpha$[32]$Time + \varepsilon$

[29] Original form of regression can be found in Appendix D
[30] There might be too many variables to estimate for such small amount of observation, however, this is because in the original model (Zhang et al., 2010) they included the quadratic terms because there is a possibility that the relationship is not linear, and the interaction terms because fixed cost may affect total cost after separation. Choosing the same variables without excluding is afraid of exclusion will cause incorrect calibration.
[31] Can be find in Appendix D
[32] α stands for the percentage of change

$$(2)$$

Assume ε follows Gauss-Markov assumption MLR. 1-5[33], thus (1) could be expanded as:

$$TCOST = \beta_0 + \beta_1 TRANSOUT + \beta_2 DISOUT + \beta_3 TRANS2 + \beta_4 DISOUT2 + \beta_5 TRANSDIS + \beta_6 PRICE\_L + \beta_7 RPRICE\_K + \beta_8 PRICE\_E + \beta_9 TRPR\_L + \beta_{10} TRPR\_K + \beta_{11} TRPR\_E + \beta_{12} DISPR\_L + \beta_{13} DISPR\_K + \beta_{14} DISPR\_E + \alpha Time + \varepsilon \quad (3)$$

By using calibration[34] we could estimate the parameters in (3), however, since the number of observations in our model is not large enough to satisfy the degree of freedom required in the model, we will estimate the relation between variables and total cost in a simplified way by omitting some of the variables[35].

$$TCOST = \beta_0 + \beta_1 TRANSOUT + \beta_2 DISOUT \quad (4)$$

Estimating (4) we would like to know how total cost is affected only by combined transmission and distribution output. From Appendix C 1 we could see, T-statistic of distribution output is insignificant to total cost. This is similar to the result of Zhang

[33] Gauss-Markov assumptions are the assumptions by Gauss-Markov states the conditions to get best linear unbiased estimators.

[34] Even though we intended to use OLS regression, the limited observation has prevented us from forming a well-fitted regression model. Thus, what we did is more similar to calibration than regression.

[35] Omitting important variables may cause bias in the model, however, we would like to see the relationship between combined transmission and distribution and the total cost under limited observations, thus we have to omit some variables.

et al. (2010). The parameter of transmission output is negative, which shows there is economies of scale in transmission network.

$$TCOST = \beta_0 + \beta_1 TRANSOUT + \beta_3 TRANS2 + \beta_5 TRANSDIS \tag{5}$$

Estimating (5) we would like to see how total cost is solely affected by transmission output with quadratic and interaction terms. From Appendix C 2 we can see that R^2 and adjusted R^2 shows there is goodness of fit.[36] From p-value we could see interaction term of transmission and distribution output is significant, it has a large positive effect on total cost. This is possibly because currently we have transmission and distribution combined. Still, the parameter of TRANSOUT is negative that does not contradicts economies of scale.

$$TCOST = \beta_0 + \beta_1 TRANSOUT + \beta_6 PRICE\_L + \beta_7 RPRICE\_K + \beta_8 PRICE\_E + \beta_9 TRPR\_L + \beta_{10} TRPR\_K + \beta_{11} TRPR\_E \tag{6}$$

Estimating (6) we can see how fixed cost of transmission lines affect total cost. The importance of fixed cost of analyzing economies of scale has been pointed out by Tirole (1998) that fixed cost is a proof of economies of scale, and excluding them perhaps will cause bias in estimation. In Appendix C 3 we can see P-value of

[36] We are aware of that due to limited amount of observations, R^2 is usually at goodness of fit.

TRPR_E shows that this variable is significant. Parameter of TRPR_E is about -27. This is also reasonable that higher price of electricity the larger transmission output might be, hence there will be much lower total cost of the power grid.

Compare with (4) and (6), parameter of TRANSOUT changed from about -1 to about -4.5. If we could exclude distribution output, it shows a more significant economies of scale, which means the higher the transmission output, the lower total cost. This is shows the total cost after separation of transmission side. Thus we can interpret by separating distribution and transmission networks, there will be more significant economies of scale on transmission enterprises.

The reason we exclude TRANSOUT2 from (6) is due to limitation of observations. When we have TRANSOUT2 included in (6), we will the following result. Appendix C 4 shows there is difficulty to tell the significance of each variable. We could regard it as calibration. From the calibration in Appendix C 4 we can observe the increasing economies of scale. Hence, we could say after separation of transmission and distribution lines, we will have larger economies of scale in transmission part.

$$\text{TCOST} = \beta_0 + \beta_2\text{DISOUT} + \beta_6\text{PRICE\_L} + \beta_7\text{PRICE\_K} + \beta_8\text{PRICE\_E} + \beta_{12}\text{DISPR\_L} + \beta_{13}\text{DISPR\_K} + \beta_{14}\text{DISPR\_E} \tag{7}$$

(7) shows the total cost of distribution enterprises after separation. From the estimation, we can also see a larger economies of scale from the distribution side, but in reverse direction. The parameter of distribution output changed from 0.47 to 4.6. It can be interpreted as after the separation, there total cost of distribution increases in a larger scale.

We excluded DISOUT2 from the estimation is also due to limitation of observation. After we involve DISOUT2 in the estimation, we can see parameter of disout is around 1.6. It still shows the increased economies of scale after separation.

Theoretically, the vertical economic loss[37] after separation would be:

Total Cost Transmission + Total Cost Distribution - Total Cost Combined

(8)

Vertical economic loss = β_0 + β_6PRICE_L + β_7RPRICE_K + β_8PRICE_E - β_5TRANSDIS + αTime + ε

(9)

Loss Ratio = Vertical economic loss / Total Cost Combined

(10)

The reason we will have larger economies of scale in distribution part is shown in (9) that after the separation, there will be additional fixed cost for distribution network

[37] Please see D2

since they shared the some of the facilities in the past. Also, factors of price will not be affected by separation, disturbance also will not be affected by separation. Interaction term TRANSDISOUT will remain unchanged. The economies of scale will be changed in both distribution and transmission part after the separation. This economies of scale is changed because first, there might be a decreased in initial cost in distribution part, second, transmission companies will sell their electricity to distribution company with marginal profit. When transmission companies sell electricity to distributional companies, the price involved will not only be part of the transmission cost, but they will raise their price to make their company profitable. This increase of cost will be additional to distributional companies.

Let θ be percentage of price increased, then, the new formula for total distribution cost will be[38]:

$$TCOST = \beta_0 + \beta_2 DISOUT + \beta_4 DISOUT2 + \beta_6 PRICE\_L + \beta_7 PRICE\_K + (1+\theta)\beta_8 PRICE\_E + \beta_{12} DISPR\_L + \beta_{13} DISPR\_K + (1+a)\beta_{14} DISPR\_E \quad (11)$$

After the increase in price of distribution, ($\theta>0$), Vertical economic loss for distribution can be expressed as:

$VEL_d = \beta_0 + \beta_6 PRICE\_L + \beta_7 RPRICE\_K + (1+a)\beta_8 PRICE\_E - \beta_5 TRANSDIS + (1+a)$

[38] This is a derivation based on Zhang et al. (2010), original derivation can be found in Appendix D 9.

β_{14}DISPR_E + β_{14}DISPR_E + αTime + ε

(12)

Thus the economic loss of distribution enterprises will be:

EL_d = VELd - VEL = θ β_8PRICE_E + θ β_{14}DISPR_E[39]

(13)

From (13) we can see, if there will be a increase in price after separation, then the cost of increased price may increase more on the distribution side according to the sign of parameter changes. The increase of fixed cost and increase in price will be both undertaken by the distribution part. This is verified by observing the parameter of DISOUT. The change of parameter from 0.46 to 1.6 has explained the effect of cost burden.

Even though there will be increase in price to distributional network, the final retail price may not be influenced. However, behind increase in price, there will be complicated problem involved in pricing mechanism. Bulk sale and other inter-grid transmission distribution maybe priced differently. Our model is separating transmission line at a national level, thus the structure of industry will be 2 head companies are responsible for transmission, and several distributional companies. Transmission companies remain regional monopolies.

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[39] Original form in Appendix D 9

3.6 Summary

Due to the limited observations and times period our result of estimation may not be very solid, but it is decent to see the relationship and change of economies of scale by calibration. We have found the economies of scale will enlarge but indifferent directions for transmission and distribution. For transmission, the economies of scale will increase, but for distribution there may be diseconnomies of scale. Compare with the original data, the change of economies of scale is similar with transmission but different with distribution. They have also economies of scale distribution sector but positive price of electricity. This may refer to the economies of scale in distribution but increasing transaction cost. Another reason may be the level of separation. When we are separating at a national UHV transmission level (800KV), the transmission companies are very specialized, the economies of scale may be more prominent (Edward and Starr, 1987). At the meantime, distribution lines are responsible for 500KV, 220KV and 110 KV, especially, for most of the provincial distribution they may not have transmission lines constructed. The indivisibility of fixed cost may be the reason to cause increasing fixed cost and lead to diseconomies of scale. (Mansfield, 1976)

We have 2 cross sections, because there are only two national power grids in China and we are analyzing at the national level. However, we still come to similar results with Zhang et al. (2010) on the transmission part. Hence, the direction of study should be correct. If there are more data obtained, this model maybe valuable for further analyzing separation of distribution and transmission at UHV level. [40]

There are 3 disadvantages of this model found by us during the estimation. First, technology assumed remain unchanged after separation. There is not proof for unchanged technology, especially when we are doing separation at the national level. Some patent rights owned by the national grids may no longer be available for distribution companies. This will generate another fixed cost. Second, the assumption of constant cost function and parameters is very idealistic. Cost function may vary in between companies, as well as the parameters. Zhang et al. assumed the cost function of each provincial grids is constant and identical, this may vary in reality. Third, the model cannot locate times change. There is not time parameter involved in the estimation. Having a static model can cause the change with time is not well traced. This will also affect the result of estimation.

[40] If we can wait a few more years, there are more UHV lines operating, it is more plausible.

4. Pricing System

4.1 General Information

In China the current pricing system includes 4 types of prices: on-grid, retail (include bulk sale), inter-grid, and cross regional. On-grid is the price that provincial level power grids or above pay to purchase electricity from independent power plants. Retail is the price when power grids sell electricity to its end users. Bulk sale is the price a city or lower level power grids purchase electricity from provincial power grids. It is normally set based on a percentage of the retail price. Shenzhen is a classic example of bulk sale price; it purchases electricity directly from the provincial power grids with special rates. Inter-grid is the price when power grids trade electricity amongst themselves. This could be regarded as special case of electricity retailing. Cross regional are the prices when regional power grids trade electricity between different regions. This type of trading normally would not involve end users.

Cost of transmission and distribution is calculated together with the other costs of the power grids, and not independently priced. To calculate the price of transmission and distribution we usually have the retail price minus the on-grid price. Thus the cost of transmission and distribution has never been clear to its consumers. When the government sets prices based on cost plus reasonable profit, it is very difficult to determine precise cost.

The new reform has clarified accounting rules for cost calculation. According to

<u>People's Republic of China Price Law</u>, *"CPC Central Committee and State Council on Further Deepen the Power System a number of Opinions "*(Zhong Fa [2015] No. 9) and *"Government Pricing Cost Supervision and Examination Measures"* (national development and reform Commission order No. 42) and other relevant provisions of the enactment:

"To strengthen the supervision of power transmission and distribution costs, the cost of going to regulate transmission and distribution pricing behavior, improve the electricity transmission and distribution to develop science, rationality and transparency."

These measures apply to the provision of transmission and distribution grid service enterprises (hereinafter referred to as grid enterprises) to implement cost supervision and examination of the pricing behavior.

Transmission and distribution pricing cost supervision and examination shall be nearly three years with the accounting firm or auditing, taxation and other government departments to audit of the annual financial report, accounting documents, books and grid investment, production and operation, approved by the government and other relevant original documents based on the information. Transmission and distribution grid enterprises shall pricing regulation need to establish and improve the cost-accounting system, according to the voltage level, services and categories of users to accurately record and reasonable imputation transmission and distribution of production and operation costs data.

Pricing will include depreciation and operation and maintenance costs. Depreciation refers to the press service of the transmission and distribution of fixed assets and related depreciation rate of certain accrued expenses. Operation and maintenance costs refer to the cost of maintaining grid enterprises grid normal operation, including materials, repairs and maintenance, staff salaries and other expenses. Specification of cost includes the salary of employees, and other R&D (research and development) costs, and what should not be included in the cost accounting.

Included in the price costs of depreciation in accordance with the principles of supervision and examination during the previous year may be depreciated transmission and distribution and pricing of fixed assets depreciation rates approved classification. Transmission and distribution can depreciation of fixed assets, means a fulfilling line with the planning necessary approvals, including the decision-making procedures for the construction of the line, substation and transmission and distribution equipment, and other business-related assets, not including the separation from the enterprise out of the auxiliary grid of the business units, a variety of business enterprises and "tertiary" assets. Approved on fixed assets in accordance with the historical cost principle. Capital verification conducted according to the provisions of fiscal value of fixed assets or state-owned assets supervision and administration department as confirmation. The following cases can not be included in the depreciation of fixed assets of the transmission and distribution range: conducted audit of the assets but not financial or state-owned assets supervision and administration departments that; users or local governments and other non-free transfer of power grid enterprises to invest in the formation of unable to provide valid proof of the value of fixed assets; revaluation of fixed assets; assets accrued after depreciation of fixed assets still in use.

Transmission and distribution of fixed asset pricing depreciated using the straight-line method. Pricing depreciation period is determined based on the factors of transmission and distribution categories of fixed assets, equipment and operating environment and so on actual usage. January 1, 2015 before the formation of the transmission and distribution of fixed assets, depreciation rate in accordance with the value pricing SGCC, CSG and the provisions of the depreciation period of fixed assets combined with the actual useful life, with reference to the implementation of other grid enterprises; 2015 January 1 and after new transmission and distribution of fixed assets, in accordance with the provisions grid unbundling fixed assets depreciation period, combined with the natural environment around the level of network development and determine the actual situation. Residual rate of fixed assets is generally calculated at 5%.

4.2 Pricing Mechanism

There are 3 common pricing mechanism used by electricity industry. First, cost-plus pricing. Cost-plus pricing method refers to a method of pricing the enterprise cost basis for pricing non-competitive products. In a fully cost-plus pricing method, the "cost" base refers to the manufacturing cost per unit of product, "bonus" content, including non-manufacturing costs (such as marketing costs and administrative costs) and profit targets. Using variable cost plus pricing method, the "cost" basis refers to variable costs per unit of product, and "bonus" content includes all fixed costs and profit goals. (Tinsley, 1965) China is currently using a modified variable cost plus pricing. Determining the additional costs on the basis of the percentage of bonus is the core issue of the cost-plus pricing method. Whether it is a completely cost-plus pricing method or the use of variable cost plus pricing method, the determined number of bonuses, in addition to providing the desired profits, are part of the need to contain the cost of the project.

Second, fixed pricing. From the point of view of the behavior, the main body to implement a fixed price behavior is the enterprise or business associations. "Enterprise" is a broad concept referring to the profit established for the purpose of economic entity, it is a legal entity, but is not limited to the legal personality of the entity is a partnership. An "enterprise", must be an independent economic entity, and they can belong to a group or have a parent-subsidiary relationship between enterprises. Enterprise is the main body of the implementation of a fixed price behavior. But in some special cases, the enterprise belongs to trade associations also possible to implement a fixed price behavior. The purpose of the implementation of a fixed price behavior, is to prevent, restrict or distort competition between members of the combination. China, before 1985, used this pricing mechanism in electricity industry. Since the fixed price is often formed by a combination of enterprises, the capital becomes concentrated in the combination. This concentration of economic power in the combination and the combined market share of the large members could further lead to a monopoly, thus stifling market forces from outside of the combination. This is certainly not suitable for forming a competitive electricity market.

Incentive pricing is the mechanism designed to balance between rent extraction and efficiency. While the new reform has regulated the auditing standard and increased information transparency, the pricing model is still based on cost plus reasonable profit. Since we have discussed the possibility of increase in retail price due to separation, there should be a new pricing mechanism found to be suitable for the new reform.

4.3 Basic Model

Since incentive pricing is never applied, there is difficulties to search for regulations, data and formula to run a empirical analysis. Here we will be simply analyze the model theoretically.

SGCC and CSG are both natural monopolies. Assume government entrusts the firm to product q units of electricity. Reversed demand function is:

$$p(q) = a - bq,\ a > 0,\ b > 0 \tag{14}$$

Consumers utility from q unit of electricity is U_c (q), $U_c' > 0$, $U_c'' > 0$, with a decreasing marginal utility.

Assume the cost function for a firm is:

$C = (b - e)\, q$, where b - e is the marginal cost, b is the parameter of adverse choice, e is effort made by the firm to lower the cost.

(15)

Social cost is l, l > 0. f(e) is the function explaining positive correlated relationship between effort made and utility.

Under perfect information, Ramsey price can be used by firms. Thus, have a market equilibrium clearance function:

$p = (b - e) / (1- e_d\, l / (1+l))$, e_d is price elasticity of demand.

(16)

Under this equilibrium, optimal f (e) = q*. q* is the equilibrium quantity. This is optimal for our model. When we have only two companies responsible for electricity transmission, classical market mechanism has lost its function of price finding. To find the proper price and providing the quantity at equilibrium level, we first need to guarantee there is perfect information. The new reform will be regulating the auditing standard to create decrease information asymmetry. Thus, theoretically, we can use incentive pricing to fix the equilibrium price level, ensure the output of natural monopolies.

5. Retailing

Through the gradual liberalization of electricity sales business, and further introduction of competition, improve the electricity market operation mechanism, give full play to the decisive role of the market in allocating resources to encourage more and more market players involved in the sale of electricity markets are the target of the new reform. Ensure fair and open electricity market, and establish a standardized purchase and sale transactions mechanism, after the government improved the pricing mechanism, release generation and sale of electricity side side ends of the transmission and distribution grid and other natural monopoly sectors and markets other subjects strictly regulated, further strengthen government regulation.

The electricity retailing companies divided into three categories, the first category is the sale of electricity grid enterprise companies. The second category is social capital increment distribution network, the distribution grid operator has the right to sell electricity company. The third category is independent of the sale of electricity companies that do not have the right to operate the distribution network, do not assume minimum guarantee supply services.

The same area of business may have multiple power supply electricity sales company, but only one company has the right to operate the distribution network, and to provide security at the end supply service. Same electricity sales company to sell electricity at a plurality of power supply business district.

The process of qualification is severe and long. Barrier of entry is relatively high that most of the private capital will not be able to entry. Barrier of entry has prevented further marketization of retailing business, however, the high standard of entry may also provide security of electricity. The minimum requirement of assets is over 20 million RMB; it also has to be approved by the provincial government with guaranteed certificate to sell electricity.

Therefore, in order to ensure that after the sale of electricity market reform can be fair competition, companies must sell electricity to the grid companies strict supervision. Power grid enterprises should be allowed to return to public welfare aspects of transmission and distribution as quickly as possible. Power companies sell electricity to the company as soon as possible into a relatively independent of the sale of electricity service provider or in-house independent grid company to make the sale of electricity and other companies have the same starting point of the competition. Allow enterprises to participate in the sale of electricity grid side competition this arrangement, only as a transitional state. Also, note that placing one's little monopoly. For the distribution grid operator has the right to sell electricity company, since the placement of integrated operation, similar to the power grid companies, but also strengthen its supervision. With the future deepening of the reform, but also placing gradual separation.

Reform of the sale of electricity side to fully protect the legitimate and reasonable rights and interests of all market participants subject, the need to strengthen institutional innovation, establish a sound regulatory system. First, the establishment of information disclosure and credit evaluation mechanism. On the one hand the establishment of information disclosure mechanism, government departments regularly publish market entry exit criteria, the transaction subject directory, the negative list, blacklist and regulatory reporting and other information, but also in the corporate market players designated website publicity company relevant information and credit commitments. On the other hand the establishment of credit evaluation mechanism, based on the enterprise market government compliance and other market behaviors establishment of credit evaluation system of market players, and the public timely evaluation results, the implementation of operational responsibilities.

Second is to strengthen supervision and risk prevention. Strengthen credit application evaluation results, efforts to prevent the sale of electricity in default risk, improve the supervision mechanism for the government to ensure fair and open electricity market, and establish a standardized purchase and sale transactions mechanism, transmission and distribution grid and other natural monopoly sectors and other subjects highly regulated market further strengthen government regulation. In the sale of electricity side of the main access to the market, credit system, risk prevention, market supervision, the Government needs to effectively carry out the supervision and guidance.

Power sale side will release the formation of a huge electricity sales market currently have Huaneng, Huadian, State Power Investment five power generation Group-owned enterprises set up electricity sales company, there are many local power companies set up electricity sales company, showing power generation companies for sale power business showed a positive response attitude. From the perspective of power plants, the sale of electricity side reform both opportunities and challenges.

Opportunity is: First, power companies can enter new distribution and sale of electricity in the field areas, homegrown, extend the industrial chain, to play the advantages of industrialization; the second is power generation companies can optimize the allocation of resources through the sale of electricity, especially for assets the larger, wider distribution of large-scale power generation enterprises, through integrated optimization, reasonable dispatch to achieve optimal allocation of resources within the enterprise, improve the profitability of the business, but also to contribute to the national energy saving; Third generation companies can fully the use of electricity sales resources to provide value-added services to create a comprehensive energy service companies to further enhance their core competitiveness.

The challenge is: First, enterprises competition further intensified, the user selects the right will result in the original business plan generating electricity tariff gone, only to seize the power generation business through customer resources to improve their competitiveness, maintain business survival; the second is the market increased risk of conventional grid company unified purchase and marketing of different power generation companies will face power users need to take social responsibility, the user defaults, arrears and other electricity market and further increase risk; Third, companies can enter the power grid electricity sales business, utilizing existing large customer resources and technical strength, the sale of electricity to other market players will create a strong competitive advantage. But on the whole, power generation companies either set up their own electricity sales company to be sold to power companies to sell electricity in the market of the new situation, the power generation business by changing the traditional business model by providing quality products and services to users to capture the market, form their own core competencies, to overcome the challenges and opportunities to meet the reform.

Conclusion

In conclusion, separation of transmission and distribution may have enlarge the economies of scale. This study has been found by this paper as well as Zhang et al. (2015). [41] The increase in fixed cost after separation has been shown in Zhang et al. (2015) studies, and we can observe the diseconomies of scale in distribution part by observing the change in parameters.[42] Our model is different from Zhang et al. (2015) in many ways, such as level of separation, number of observation, number of estimated variable and significance of change in economies of scale. However, the difference does not affect the enlargement in economies of scale after all.

There are limits in Zhang et al. (2015) 's model. To have more realistic estimations we may need to change some parameters of our model. However, this model has illustrated the effect of separation on economies of scale. By having this model, we can further consider the separation of transmission and distribution in two ways. First, consider which level of grid to separate. From the result of our research and Zhang et al. (2010)'s research, separation at UHV level and provincial level has different outcome of economies of scale. They differ in significance of change and direction of change for distribution companies. Second, is the mechanism of pricing. If there is increase in fixed cost, the government should have well-formed mechanism to avoid transmission companies from inequilibrium price and over-burden of distribution

[41] This statement is also supported by Edwards and Starr (1976)

[42] We did not estimate the change in fixed cost because of limited data, but it is indicated by considering Tirole (1988) and Mansfied (1976).

companies.

To have good result from the reform, the administration department has to be very careful in implementation. Separating distribution and transmission sections, generate a competitive electricity distribution market is the main target of this reform. By having incentive pricing, transmission enterprises will have the motivation to maintain its production at the market equilibrium level. Keeping the transmission enterprises supply stable and secure, there will be less dead-weight loss and we will have better outcome of resource allocation and energy efficiency.

Bibiliography

1. Scherer, Charles R.. 1976. Estimating Peak and Off-peak Marginal Costs for an Electric Power System: An Ex Ante Approach. *The Bell Journal of Economics* 7 (2). [RAND Corporation, Wiley]: 575–601.

2. Chen and Xu, 2005. The reform of electricity power sector in the PR of China, Shaofeng Xu, Wenying Chen. Energy Policy 34 (2006) 2455–2465

3. IEA, 2012. "Renewable Energy Market Trends and Projections to 2017"

4. OIEA, 2016. China's Coal Market - Can Beijing Tame 'King Coal? - Oxford Institute for Energy Studies." Oxford Institute for Energy Studies. Accessed May 08, 2016.
https://www.oxfordenergy.org/publications/chinas-coal-market-can-beijing-tame-king-coal/.

5. Fan et al., 2012 樊扬，林勇，徐乾耀，张宁，陈新宇，2012"广东电网风电出力特性分析及其经济性评价"，南方电网技术，2012 年 第六卷 第一期

6. SDPC, 2009. "关于整顿规范电价秩序的通知(发改价检[2011]1311 号)"，中国国家发展改革委员会，2009

7. CEG, 2014. Key China Energy Statistics, China Energy Group,2014

8. Stiglitz, Joseph E. 1988. Economics of the Public Sector. New York: W.W. Norton, 1988.

9. Air Quality Index Organization, http://aqicn.org/city/beijing/

10. Stat PKU, 2015. "空气质量评估报告 北京城区 2010-2014 年 PM2.5 污染状况研究 从统计学的视角解读北京雾霾",北京大学统计科学中心 北京大学光华管理学院，二零一五年三月

11. "我国碳排放 2030 年达峰值——中国政府网". 2016. *Gov.Cn*. http://www.gov.cn/xinwen/2016-03/08/content_5050594.htm.

12. Zhu Liu. 2015. "China's Carbon Emissions Report 2015." Sustainability Science Program and Energy Technology Innovation Policy research group, Belfer Center Discussion Paper #2015-02. Harvard Kennedy School of Government, Cambridge, MA.

13. Mastny, Lisa. Renewable Energy and Energy Efficiency in China: Current Status

and Prospects for 2020. Washington, D.C.: Worldwatch Institute, 2010.

14. CNREC (2013a), 2012 China Renewable Energy Outline, December 2013, CNREC, Beijing, China

15. Medium-Term Renewable Energy Market Report 2012 Market Trends and Projections to 2017. Paris: OECD Publishing, 2012.

16. Chinese Renewable Energy Industries Association (CREIA)， Chinese Wind Energy Association (CWEA)， Global Wind Energy Council (GWEC)， 2014. 中国能源体制改革研究报告 能源安全与国家发展研究中心 北京大学国家发展研究院 2014 年 5 月

17. MARTÍNEZ-BUDRÍA, E., S. JARA-DÍAZ, and F. J. RAMOS-REAL. 2003. "Adapting Productivity Theory to the Quadratic Cost Function. An Application to the Spanish Electric Sector". *Journal of Productivity Analysis* 20 (2). Springer: 213–29. http://www.jstor.org/stable/41770130.

18. Klemperer, Paul. Auctions: Theory and Practice. Princeton: Princeton University Press, 2004.

19. IEA, 1999. Coal in the Energy Supply of China

20. Tinsley P.A., 1965 "On the Flexibility of Cost Plus Pricing", Econometric Research Program Research Memoriandum No. 75, April 9, 1965

21. SGCC, 2013. "China Energy News: China Ready for Large-scale Construction of UHV, State Grid Corporation", 2013 http://www.sgcc.com.cn/ywlm/mediacenter/inspotlight/10/297984.shtml

22. SDPC, 2016"关于规范电能交易价格管理等有关问题的通知 （发改价格[2009]2474 号）"，2016. 中国国家发展改革委员会. http://www.sdpc.gov.cn/zwfwzx/zfdj/jggg/200910/t20091026_308846.html

23. He. Xin, 2003. The Development and Status of the Power Grid in China and International Cooperation for Grid Integration in Northeast Asia,State Grid Corporation of China.

24. Edwards, Brian K., and Ross M. Starr. 1987. A Note on Indivisibilities, Specialization, and Economies of Scale. *The American Economic Review* 77 (1). American Economic Association: 192–94. http://www.jstor.org/stable/1806738.

25. Mansfield, Edwin,1976 Microeconomics -Theory and Applications (Shorter 2nd ed.), New York: W. W. Norton, 1976

26. Buchanan, 1982 "Readers' Forum, Comments on 'The Tradition of Spontaneous Order' by Norman Barry"Readers Forum, Comments on The Tradition of Spontaneous Order by Norman Barry. Accessed May 11, 2016. http://www.econlib.org/library/Essays/LtrLbrty/bryRF1.html.

27. Document No. 5，2002 《电力体制改革方案》(国发[2002]5 号文件), 中国国务院

28. Smith, Adam. An Inquiry into the Nature and Causes of the Wealth of Nations By Adam Smith .. London: Printed for W. Strahan; and T. Cadell, 1784.

29. Xiao et al., 2010. "甘肃酒泉风电出力特性分析" 肖创英, 汪宁渤, 陟 晶, 丁坤, 甘肃省电力公司,电力系统自动化，第 34 卷，第 17 期，2010 年 9 月 10 日

30. Delmon, Jeffrey, 2009. Private Sector Investment in Infrastructure: Project Finance, PPP Projects and Risks. Alphen Aan Den Rijn, The Netherlands: Kluwer Law International, 2009.

31. Shang, 2010 尚 琪,邹存国,周少磊.2010, 煤炭的真实成本-大气污染与公众健康

32. Information Office of the State Council of the People's Republic of China，2010. China's Energy Conditions and Policies.

33. Liu Xiying and Kong Lingcheng, 2016. A New Chapter in China's Electricity Market Reform, Energy Studies Institute

34. Li Junfeng,Cai Fengbo,Qiao Liming,Wang Jixue,Gao Hu, Tang Wenqian,Peng Peng,Geng Dan,Li Xiuqin,Li Qionghui,2014. China Wind Power Review and Outlook.

35. NDRC-JP,2015. 风电出力特性,北京计鹏咨询有限公司

36. Suo, Wei. 2016. 索炜， 2016. 盘点国家电网"十二五"成就——特高压国际领先 "全球能源互联网"世界影响， 新华网 http://news.xinhuanet.com/energy/2016-01/15/c_1117792099_2.htm

37. Wang, 2010 王强， 2010. "国网帝国". Antimonopolylaw.Org. http://www.antimonopolylaw.org/article/default.asp?id=1548.

38. The Climate Group, 2011 气候组织，2011. "智能电网在中国发展的现状与展望"。政策简报，第 3 期， 2011 年 4 月

39. SDPC, 2015. 国家发展改革委关于完善跨省跨区电能交易价格形成机制有关问题的通知, 发改价格[2015]962 号.

40. SDPC, 2015. 国家发展改革委关于降低燃煤发电上网电价和一般工商业用电价格的通知, 发改价格[2015]3105 号.

41. Document No. 9, 2015. 关于进一步深化电力体制改革的若干意见，中发[2015], 9 号

42. SDPC, 2015. 关于电力交易机构组建和规范运行的实施意见，中发[2015], 9 号

43. Li, Gao, 2014. 李昂，高瑞泽， 2014. 论电网公司市场势力的削弱，中国工业经济，第 6 期，2014 年 6 月

44. IRENA, 2014. Renewable Power Generation Cost in 2014.

45. SDPC, 201. 输配电定价成本监审办法, 发改价格[2015] 1347 号

46. Berrah. Noureddine ， 2009. Reforming China’s Power Sector: In the Middle of the River，Standford Center For International Development.Working Paper No. 392.

47. IEA, 2006. China’s Power Sector Reforms Where to Next?

48. Edwards, Brian K., and Ross M. Starr. 1987. “A Note on Indivisibilities, Specialization, and Economies of Scale”. *The American Economic Review* 77 (1). American Economic Association: 192–94. http://www.jstor.org/stable/1806738.

49. IBM，2006 . “建设智能电网创新运营管理-中国电力发展的新思路”，IBM 全球企业咨询服务部

50. Mansfield, Edwin, 1976. Microeconomics -Theory and Applications (Shorter 2nd ed.), New York: W. W. Norton, 1976

51. Hunt,S.，2002.Making Competition Work in Electricity.John Wiley＆Sons,Inc.

52. Hunt,S.and Shuttleworth,G.， 1996.Competition and Choice in Electricity.John Wiley＆Sons,Inc.

53. Joskow,P.And Schmalensee,R.，1983.Markets for Power：An Analyssis of Electric Utility Deregulation.Cambraidge,MA： The MIT Press.

54. Weiss,W.， 1975， “Antitrust in the Electric Power Industry.”In Phillips,Almarin（ed.）Promoting Competition in Regulated Markets,pp.135-173， Washington,DC：

Brookings Institution.

55. Tirole,J.，1988.The Theory of Industrial Organization.Cambridge,MA：The MIT Press.

56. Baldick,R.and Kahn,E.，1993，“Network Costs and the Regulation of Wholesale Competition in Electric Power.”Journal of Regulatory Economics，5，pp.367-384.

57. Zhang, et al. 2010 张昕竹，冯永晟，马源， 2010. 中国电网管理体制改革研究，江西人民出版社

58. Wang，2012 王含春，李孟刚，2012. 中国电力产业价格规制改革研究，经济科学出版社

59. SGCC, Statistic Year Book 2011-2014, 中国年鉴网络出版总库

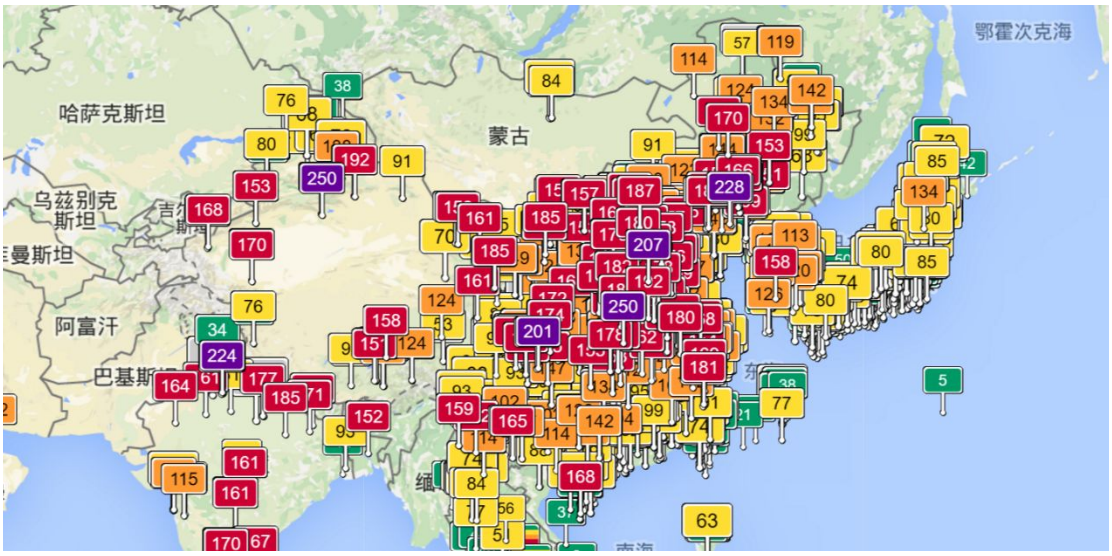
60. CDG, Statistic Year Book 2011-2014，中国年鉴网络出版总库

61. SGCC, Annual Audit Report, 2011-2014，数据审计报告，中寅华寅五洲会计所

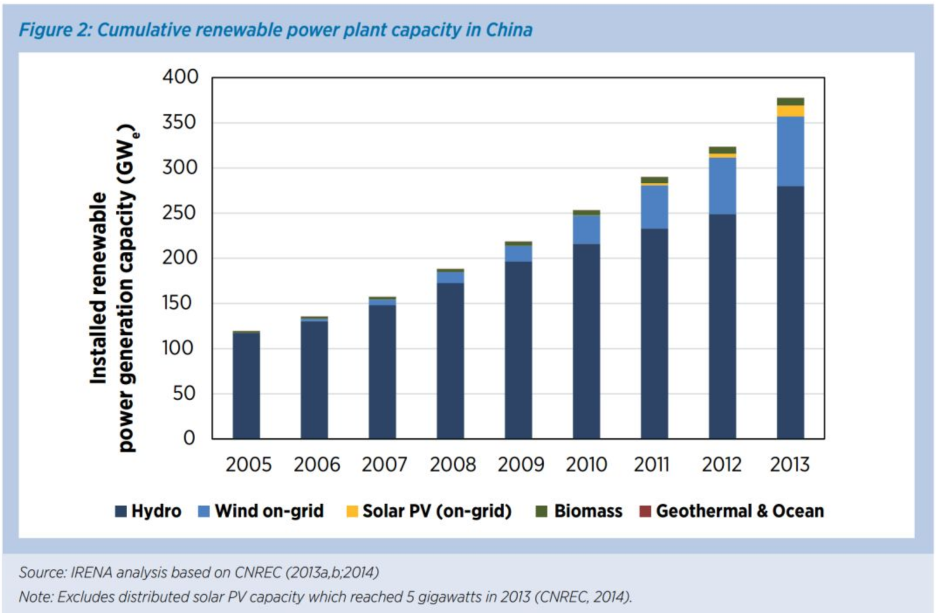
62. CSG, Annual Audit Report, 2011-2014，数据审计报告，中寅华寅五洲会计所

63. LNBL, 2014. Wind Technologies Market Report, U.S. Department of Energy

Appendix A.List of Figures

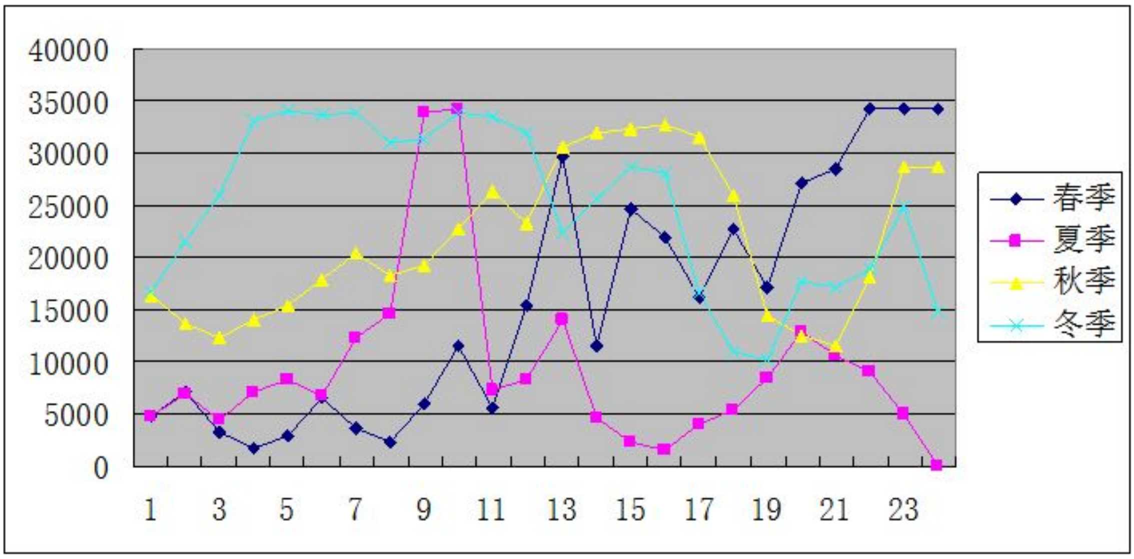


Appendix A 1



Since 2013, China has the largest total electric power production capacity worldwide which is expected to more than double by 2030

Appendix A 2



Appendix A 3

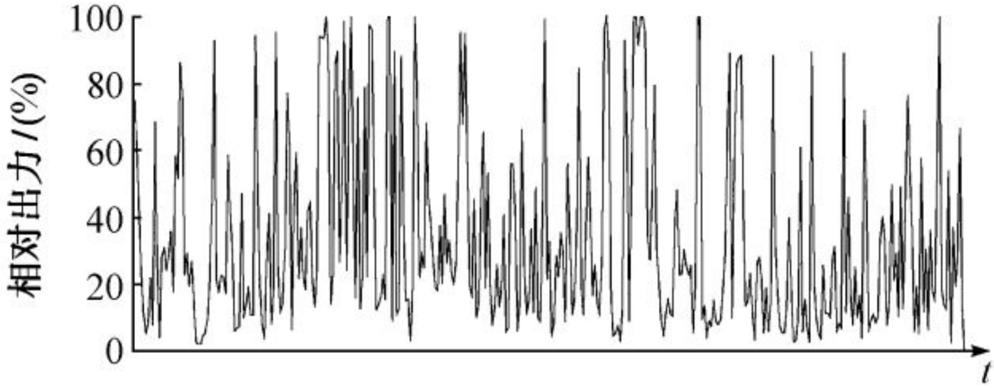


图 1 日平均出力的年度分布

. 1 Annual distribution of daily wind generation energy

Appendix A 4

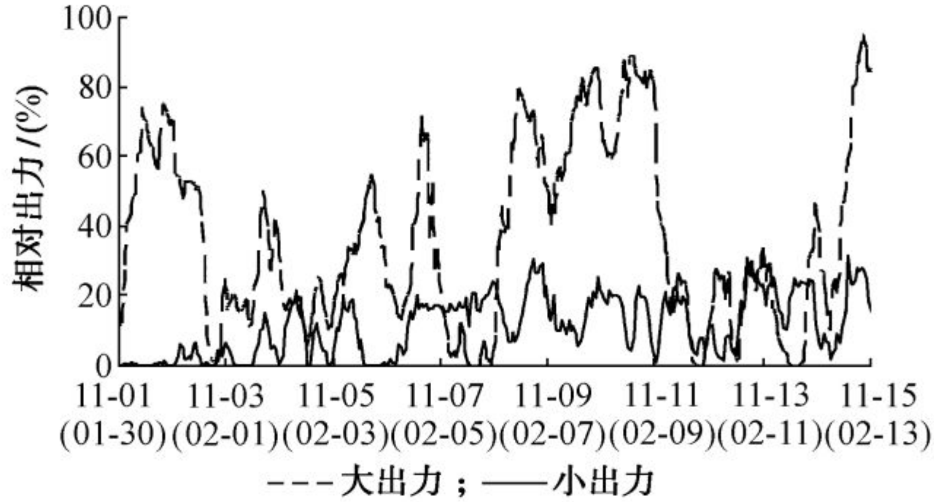


图 2　2009 年连续 15 d 风电大(小)出力

Fig. 2　Heavy/light generation of wind power in continuous 15 days in 2009

Appendix A 5

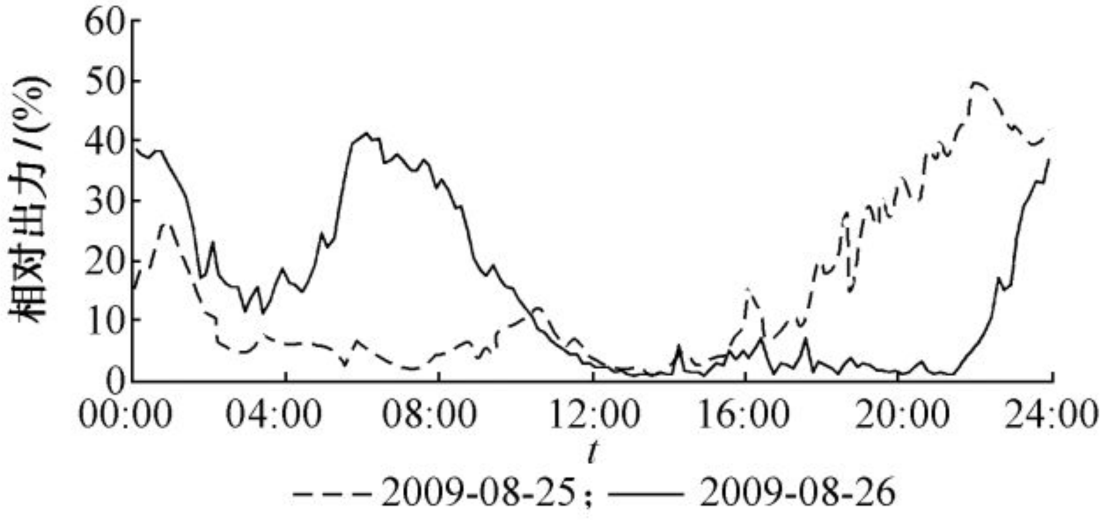
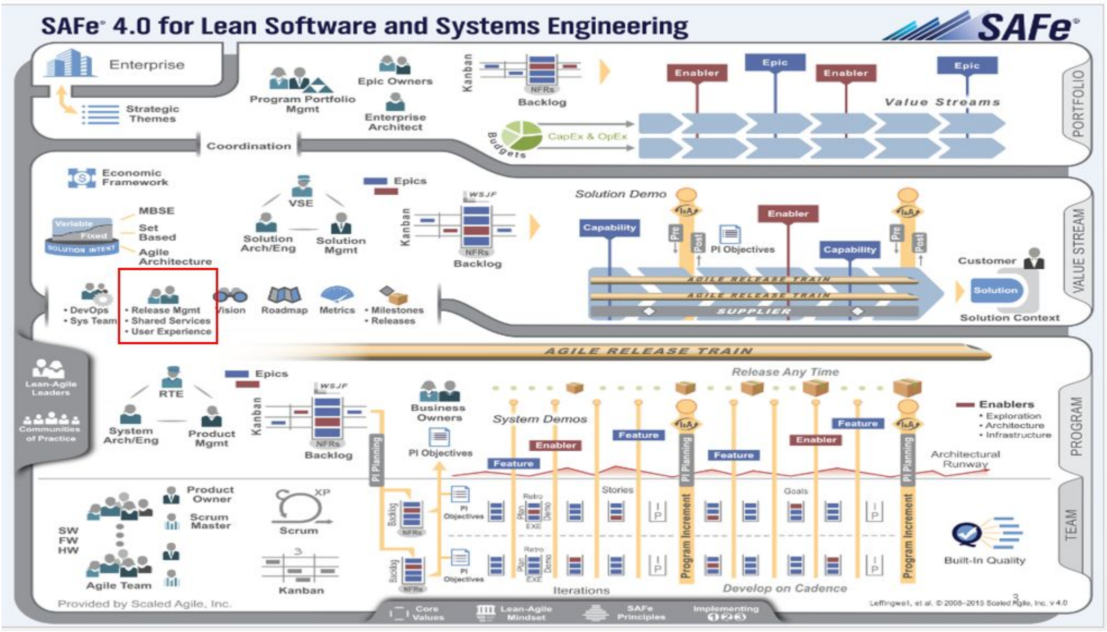


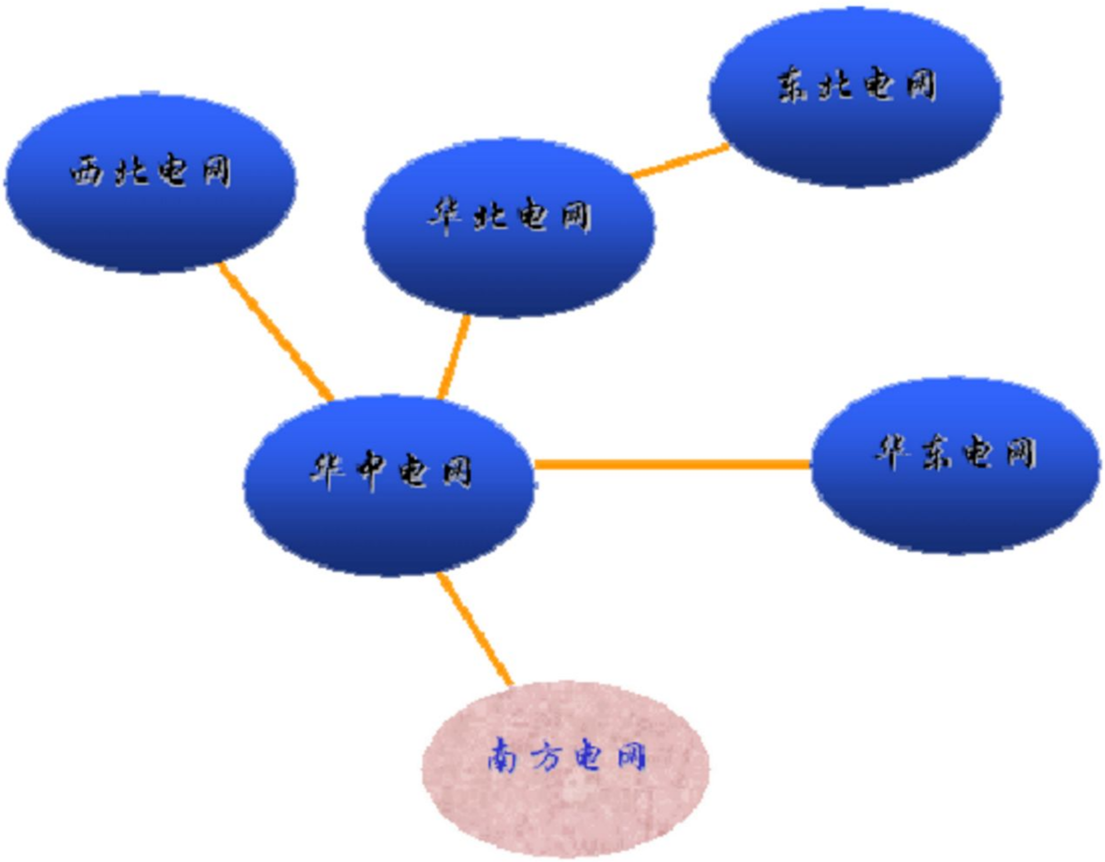
图 3　典型相邻日的风电出力曲线

ig. 3　Curves of wind power generation in two typical adjacent days

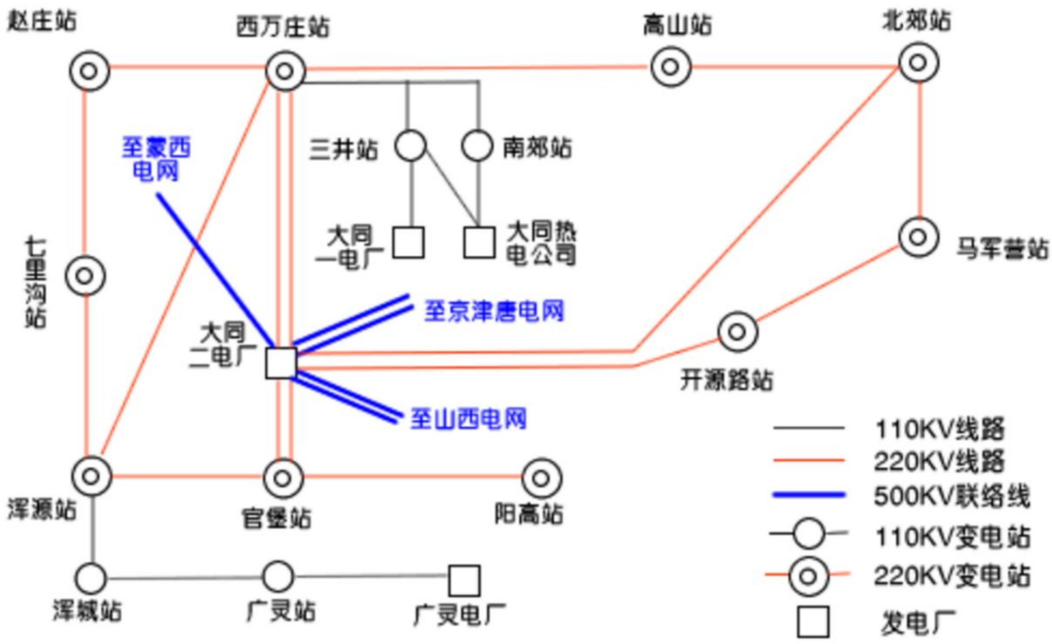
Appendix A 6



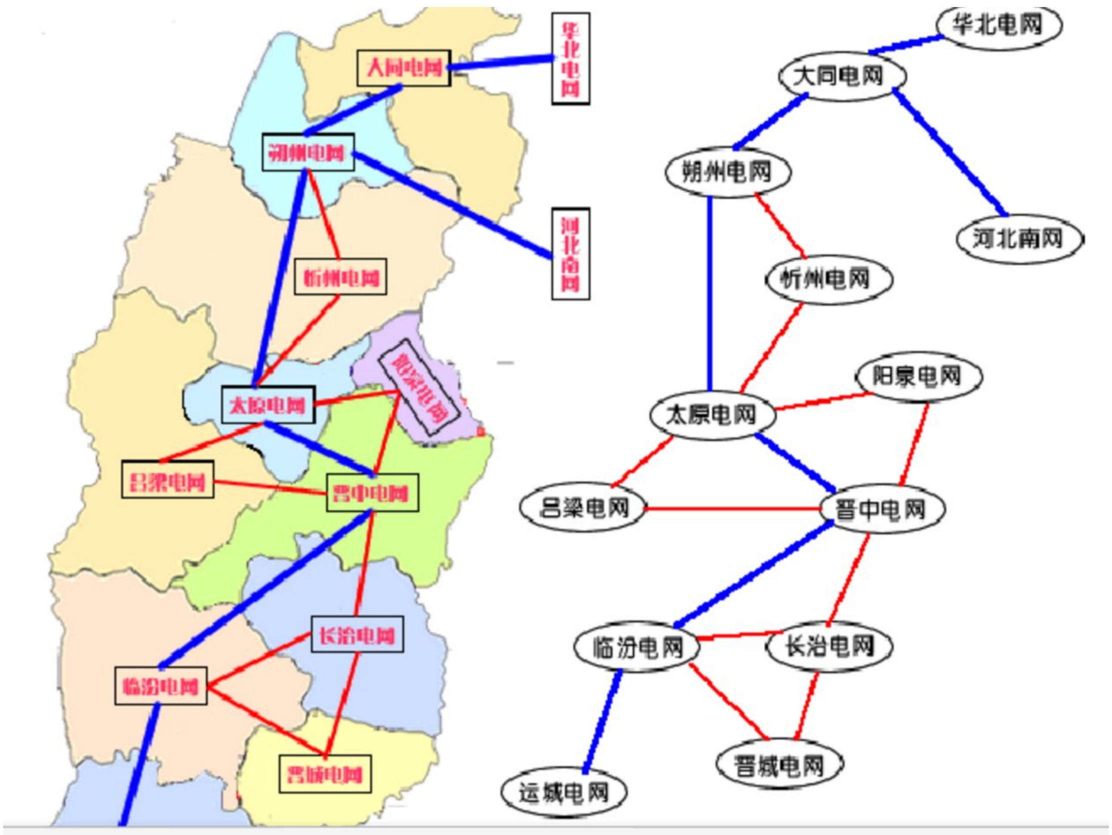
Appendix A 7



Appendix A 8



Appendix A 9



Appendix A 10

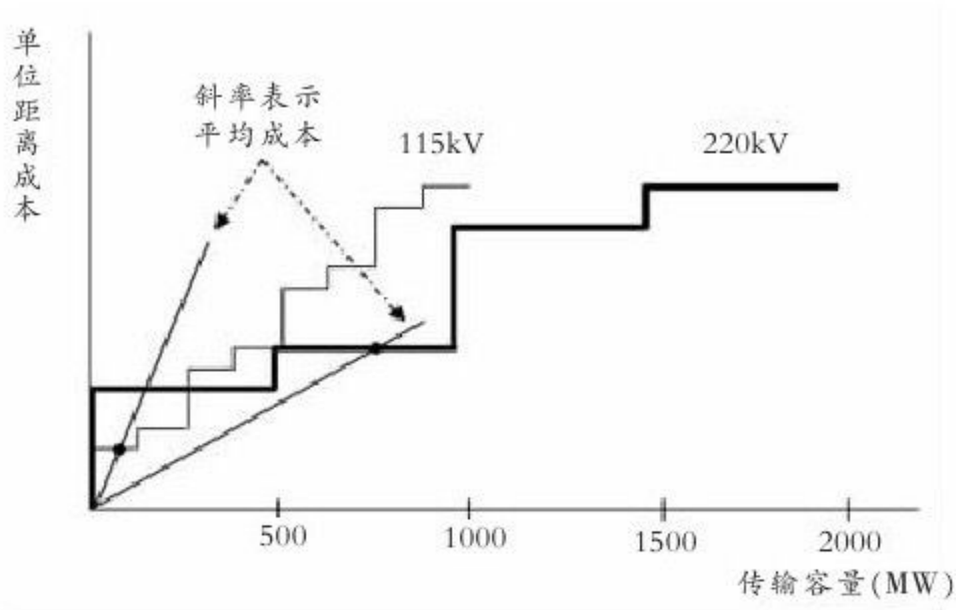
Appendix B: List of Graphs and Tables

单位：元/千瓦时（含税）

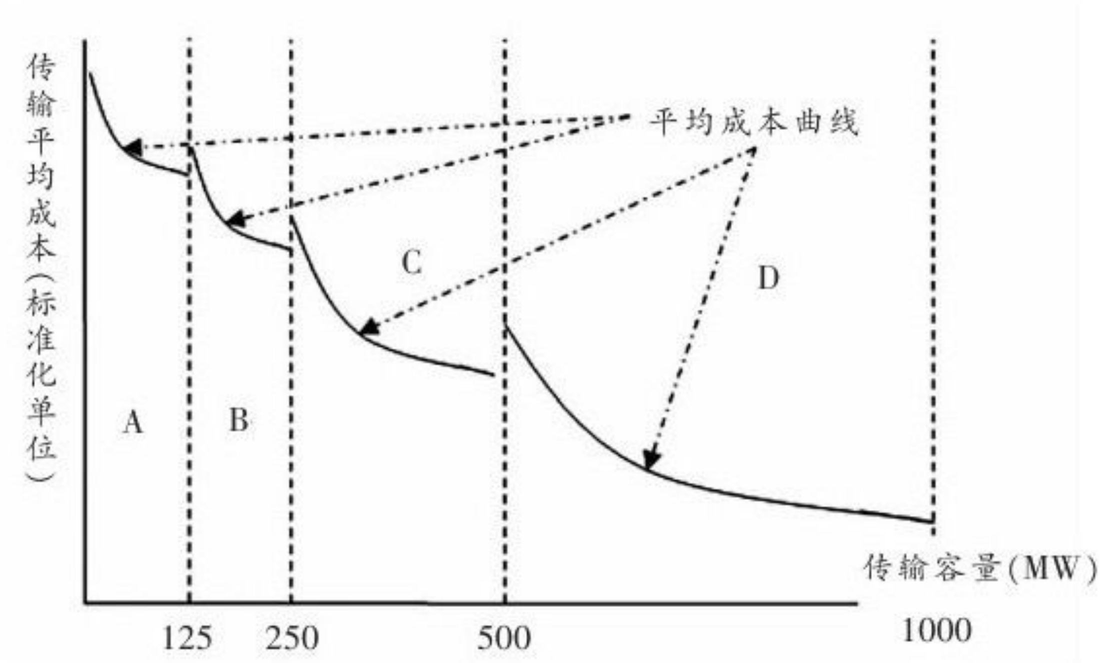
省级电网	统调燃煤发电上网电价平均降低标准	一般工商业用电价格平均降低标准	调整后的燃煤发电标杆上网电价	提高后的可再生能源电价附加征收标准
北京	0.0239	0.0000	0.3515	0.0190
天津	0.0301	0.0313	0.3514	0.0190
冀北	0.0337	0.0310	0.3634	0.0190
冀南	0.0417	0.0309	0.3497	0.0190
山西	0.0333	0.0609	0.3205	0.0190
山东	0.0465	0.0415	0.3729	0.0190
蒙西	0.0165	0.0118	0.2772	0.0190
辽宁	0.0178	0.0117	0.3685	0.0190
吉林	0.0086	0.0000	0.3717	0.0190
黑龙江	0.0141	0.0130	0.3723	0.0190
蒙东	0.0033	0.0000	0.3035	0.0190
上海	0.0311	0.0212	0.4048	0.0190
江苏	0.0316	0.0312	0.3780	0.0190
浙江	0.0300	0.0447	0.4153	0.0190
安徽	0.0376	0.0428	0.3693	0.0190

福建	0.0338	0.0204	0.3737	0.0190
湖北	0.0435	0.0300	0.3981	0.0190
湖南	0.0249	0.0108	0.4471	0.0190
河南	0.0446	0.0557	0.3551	0.0190
四川	0.0390	0.0060	0.4012	0.0190
重庆	0.0417	0.0203	0.3796	0.0190
江西	0.0403	0.0362	0.3993	0.0190
陕西	0.0450	0.0517	0.3346	0.0190
甘肃	0.0272	0.0139	0.2978	0.0190
青海	0.0123	0.0000	0.3247	0.0190
宁夏	0.0116	0.0316	0.2595	0.0190
广东	0.0230	0.0058	0.4505	0.0190
广西	0.0284	0.0150	0.4140	0.0190
云南	0.0205	0.0030	0.3358	0.0190
贵州	0.0346	0.0000	0.3363	0.0190
海南	0.0330	0.0103	0.4198	0.0190

Appendix B 1



Appendix B 2



Appendix B 3

Appendix C: Estimations by EViews

Dependent Variable: TCOST
Method: Panel Least Squares
Date: 05/09/16 Time: 03:29
Sample: 2011 2014
Periods included: 4
Cross-sections included: 2
Total panel (balanced) observations: 8

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-67186.13	37727.74	-1.780815	0.1351
TRANSOUT	-1.067096	0.975060	-1.094390	0.3237
DISOUT	0.469080	0.072844	6.439518	0.0013

R-squared	0.910281	Mean dependent var	167122.5
Adjusted R-squared	0.874393	S.D. dependent var	115613.1
S.E. of regression	40974.55	Akaike info criterion	24.35929
Sum squared resid	8.39E+09	Schwarz criterion	24.38908
Log likelihood	-94.43715	Hannan-Quinn criter.	24.15836
F-statistic	25.36465	Durbin-Watson stat	1.202169
Prob(F-statistic)	0.002411		

Appendix C 1

Dependent Variable: TCOST
Method: Panel Least Squares
Date: 05/09/16 Time: 03:39
Sample: 2011 2014
Periods included: 4
Cross-sections included: 2
Total panel (balanced) observations: 8

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	212629.1	103019.3	2.063974	0.1080
TRANSOUT	-11.60326	7.151541	-1.622484	0.1800
TRANSOUT2	1.51E-07	9.40E-05	0.001601	0.9988
TRANSDISOUT	1.56E-05	5.30E-06	2.935277	0.0426

R-squared	0.756447	Mean dependent var	167122.5
Adjusted R-squared	0.573783	S.D. dependent var	115613.1
S.E. of regression	75478.36	Akaike info criterion	25.60793
Sum squared resid	2.28E+10	Schwarz criterion	25.64765
Log likelihood	-98.43173	Hannan-Quinn criter.	25.34003
F-statistic	4.141183	Durbin-Watson stat	1.256736
Prob(F-statistic)	0.101733		

Appendix C 2

Dependent Variable: TCOST
Method: Panel Least Squares
Date: 05/10/16 Time: 00:10
Sample: 2011 2014
Periods included: 4
Cross-sections included: 2
Total panel (balanced) observations: 8

Variable	Coefficient	Std. Error	t-Statistic	Prob.
TRANSOUT	-4.482255	3.840546	-1.167088	0.4510
PRICE_L	8.95E-07	3.14E-06	0.285207	0.8231
PRICE_K	-6300023.	511677.3	-12.31249	0.0516
PRICE_E	2441777.	135081.0	18.07639	0.0352
TRPR_L	-8.98E-11	7.63E-11	-1.177626	0.4482
TRPR_K	148.1879	13.23655	11.19535	0.0567
TRPR_E	-27.09342	11.92876	-2.271269	0.2640

R-squared	0.999049	Mean dependent var	167122.5
Adjusted R-squared	0.993346	S.D. dependent var	115613.1
S.E. of regression	9431.000	Akaike info criterion	20.81195
Sum squared resid	88943762	Schwarz criterion	20.88146
Log likelihood	-76.24780	Hannan-Quinn criter.	20.34312
Durbin-Watson stat	3.224140		

Appendix C 3

Dependent Variable: TCOST
Method: Panel Least Squares
Date: 05/10/16 Time: 00:33
Sample: 2011 2014
Periods included: 4
Cross-sections included: 2
Total panel (balanced) observations: 8
WARNING: estimated coefficient covariance matrix is of reduced rank

Variable	Coefficient	Std. Error	t-Statistic	Prob.
TRANSOUT	-33.45420	NA	NA	NA
TRANSOUT2	-0.000489	NA	NA	NA
PRICE_L	3.65E-05	NA	NA	NA
PRICE_K	-4525882.	NA	NA	NA
PRICE_E	1187977.	NA	NA	NA
TRPR_L	-1.22E-09	NA	NA	NA
TRPR_K	83.73889	NA	NA	NA
TRPR_E	148.9439	NA	NA	NA

R-squared	1.000000	Mean dependent var	167122.5
S.D. dependent var	115613.1	Akaike info criterion	-27.60125
Sum squared resid	6.53E-14	Schwarz criterion	-27.52180
Log likelihood	118.4050	Hannan-Quinn criter.	-28.13705
Durbin-Watson stat	3.387109		

Appendix C 4

Dependent Variable: TCOST
Method: Panel Least Squares
Date: 05/13/16 Time: 08:40
Sample: 2011 2014
Periods included: 4
Cross-sections included: 2
Total panel (balanced) observations: 8

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	52371.57	174365.3	0.300356	0.7789
DISOUT	-0.125388	0.751655	-0.166816	0.8756
DISOUT2	5.66E-07	6.86E-07	0.825079	0.4557
TRANSDISOUT	-1.50E-06	1.42E-06	-1.059180	0.3492

R-squared	0.918587	Mean dependent var	167122.5
Adjusted R-squared	0.857528	S.D. dependent var	115613.1
S.E. of regression	43638.77	Akaike info criterion	24.51213
Sum squared resid	7.62E+09	Schwarz criterion	24.55185
Log likelihood	-94.04853	Hannan-Quinn criter.	24.24423
F-statistic	15.04410	Durbin-Watson stat	0.956550
Prob(F-statistic)	0.012085		

Appendix C 5

Dependent Variable: TCOST
Method: Panel Least Squares
Date: 05/10/16 Time: 00:41
Sample: 2011 2014
Periods included: 4
Cross-sections included: 2
Total panel (balanced) observations: 8

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DISOUT	4.604292	3.994091	1.152776	0.4549
PRICE_L	-0.000406	0.000383	-1.059414	0.4816
PRICE_K	18301634	19410765	0.942860	0.5187
PRICE_E	-5642632.	5794122.	-0.973855	0.5084
DISPR_L	4.78E-10	4.53E-10	1.055806	0.4827
DISPR_K	-39.62163	42.07179	-0.941762	0.5191
DISPR_E	0.368826	2.512587	0.146791	0.9072

R-squared	0.985966	Mean dependent var	167122.5
Adjusted R-squared	0.901765	S.D. dependent var	115613.1
S.E. of regression	36235.96	Akaike info criterion	23.50405
Sum squared resid	1.31E+09	Schwarz criterion	23.57356
Log likelihood	-87.01620	Hannan-Quinn criter.	23.03522
Durbin-Watson stat	2.856129		

Appendix C 6

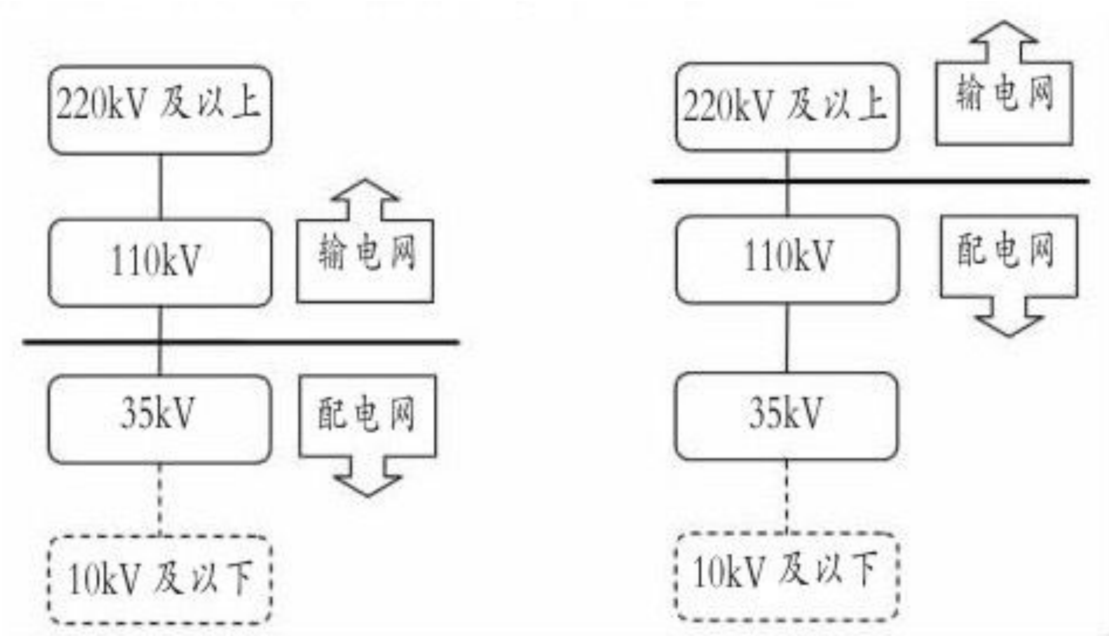
Dependent Variable: TCOST
Method: Panel Least Squares
Date: 05/10/16 Time: 00:52
Sample: 2011 2014
Periods included: 4
Cross-sections included: 2
Total panel (balanced) observations: 8
WARNING: estimated coefficient covariance matrix is of reduced rank

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DISOUT	1.611343	NA	NA	NA
DISOUT2	2.01E-06	NA	NA	NA
PRICE_L	-0.000255	NA	NA	NA
PRICE_K	5639453.	NA	NA	NA
PRICE_E	-290717.8	NA	NA	NA
DISPR_L	3.03E-10	NA	NA	NA
DISPR_K	-11.76952	NA	NA	NA
DISPR_E	-5.630347	NA	NA	NA

R-squared	1.000000	Mean dependent var	167122.5
S.D. dependent var	115613.1	Akaike info criterion	-27.83585
Sum squared resid	5.17E-14	Schwarz criterion	-27.75640
Log likelihood	119.3434	Hannan-Quinn criter.	-28.37165
Durbin-Watson stat	1.952034		

Appendix C 7

Appendix D: Estimation by Zhang et al., (2010)



Appendix D 1

表 9　样本数据基本统计量表

	变量		单位	统计量				
				最大值	最小值	平均值	峰度	偏度
成本	成本	TCOST	十亿元	74.41	3.38	19.96	3.38	1.68
	输电量	OUTPUT_T	MMWh	198.59	13.70	59.55	2.77	1.45
	输电线路长度(110kV)	LENGTH_T	kkm	12.23	1.06	5.96	-0.96	0.06
	输电线路长度(220kV)	LENGTH_T	kkm	21.50	1.91	12.32	-0.94	-0.24
	配电量	OUTPUT_D	MMWh	184.47	12.91	55.66	2.52	1.43
	配电线路长度(110kV)	LENGTH_D	kkm	21.48	3.38	11.82	-1.19	0.28
	配电线路长度(220kV)	LENGTH_D	kkm	14.05	0.00	5.46	-0.93	0.68
	劳动价格	PRICE_L	万元/人	7.74	1.84	3.73	1.19	1.08
	资本价格	PRICE_K	%	0.08	0.02	0.06	3.85	-1.76
	购电价格	PRICE_E	元/MMh	376.59	162.17	250.72	-0.39	0.29
需求	工业需求	Q_I	MMWh	1322.60	46.10	302.24	9.90	2.75
	工业价格	P_I	元/MMh	626.99	281.62	443.97	-0.64	-0.01
	工业增加值	INC_I	亿元	8118.99	95.23	1851.88	3.23	1.72
	居民需求	Q_R	MMWh	201.60	4.75	48.17	5.17	1.92
	居民价格	Q_R	元/MMh	571.33	322.99	420.13	-0.08	0.54
	人均可支配收入	INC_R	元	18645.03	6530.48	8879.25	4.42	2.14

Appendix D 2

表 10 成本函数变量含义及符号定义

变量含义	符号	简化符号
总成本	TCOST	C
输电产出	TRANSOUT	T
配电产出	DISOUT	D
输电产出平方	TRANSOUT2	T^2
配电产出平方	DISOUT2	D^2
输配交出交叉项	TRANSDISOUT	TD
劳动价格	PRICE_L	P_L
资本价格	PRICE_K	P_K
购电价格	PRICE_E	P_E
输电产出与劳动价格乘积	TRPR_L	TP_L
输电产出与资本价格乘积	TRPR_K	TP_K
输电产出与购电价格乘积	TRPR_E	TP_E
配电产出与劳动价格乘积	DISPR_L	DPL
配电产出与资本价格乘积	DISPR_K	DP_K
配电产出与购电价格乘积	DISPR_E	DP_E
华北区域变量	REGNDUM1	R_1
东北区域变量	REGNDUM1	R_2
华东区域变量	REGNDUM1	R_3
华中区域变量	REGNDUM1	R_4
2003 时间变量	YEARDUM1	Y1

Appendix D 3

Assume cost function for provincial grids is:

C = C (y; w)

Y = (T, D)[43]

C (T, D; w) < C (T, 0; w) + C (0, D; w)

(D1)[44]

VVE = C (T, 0; w) + C (0, D; w) - C (T, D; w)

(D2)

VE = (T, D; w) = [C (T, 0; w) + C (0, D; w) - C (T, D; w)] / [C (T, 0; w)]

43 T: transmission, D: distribution. The total output of grids is measured by the combined output of transmission and distribution

44 Assume combined cost is lower than stand-alone cost

(D3)[45]

$$C = \alpha_0 + (\beta_1 P_L + \beta_2 P_L + \beta_3 P_L) + (\gamma_1 R_1 + \gamma_2 R_2 + \gamma_3 R_3 + \gamma_4 R_4 + \gamma_5 Y_1 + \gamma_6 Y_2)$$

$$+ (\alpha_1 T + \alpha_2 D + \alpha_{11} T^2 + \alpha_{22} D^2 + \alpha_{12} TD)$$

$$+ (\beta_{11} TP_L + \beta_{12} TP_K + \beta_{13} TP_E + \beta_{21} DP_L + \beta_{22} DP_P + \beta_{23} DP_E)$$

(D4)[46]

Total CostAfter Separation:

$$C_T = \alpha_0 + \alpha_1 T + \alpha_{11} T^2 + \beta_1 P_l + \beta_2 P_k + \beta_3 P_e + \beta_{11} TP_l + \beta_{12} TP_k + \beta_{13} TP_e + \gamma_1 R_1 + \gamma_2 R_2 + \gamma_3 R_3 + \gamma_4 R_4 + \gamma_5 Y_1 + \gamma_6 Y_2$$

(D5)

$$C_D = \alpha_0 + \alpha_1 D + \alpha_{11} D^2 + \beta_1 P_l + \beta_2 P_k + \beta_3 P_e + \beta_{21} DP_l + \beta_{22} DP_k + \beta_{23} DP_e + \gamma_1 R_1 + \gamma_2 R_2 + \gamma_3 R_3 + \gamma_4 R_4 + \gamma_5 Y_1 + \gamma_6 Y_2$$

(D6)

Marginal Cost After Separation:

$$C_T = \alpha_1 + 2\,\alpha_{11} T + \beta_{11} P_l + \beta_{12} P_k + \beta_{13} P_e \qquad \text{(D7)}$$

$$C_D = \alpha_1 + 2\,\alpha_{11} D + \beta_{21} P_l + \beta_{22} P_k + \beta_{23} P_e$$

(D8)

Result of Estimation for Parameters:

[45] If VE > 0, there is less cost to have combine; if VE > 0, there is more cost to have separation

[46] First line refers to fixed cost when transmission and distribution are combined; second line and third line shows the variable cost of combined distribution and transmission

变量	情景 1	
	估计值	标准差
CONS	***4.8697	1.0914
TRANSOUT	***−0.0057	0.0021
DISOUT	−0.0011	0.0050
TRANSOUT2	***1.07E−06	5.28E−07
DISOUT2	**4.99E−06	2.95E−06
TRANSDISOUT	**−2.62E−06	1.49E−06
PRICE_L	−1.4683	1.9977
PRICE_K	***−802.01	224.61
PRICE_E	***0.2743	0.0936
TRPR_L	**0.0163	0.0088

Appendix D 4

Total cost function of combined transmission and distribution:

$$
\begin{aligned}
C = {} & 4.8697 - 0.0057 * TRANSOUT - 0.0011 * DISOUT \\
& + 0.000001 * TRANSOUT2 + 0.000005 * DISOUT2 - 0.000003 * TRANSDISOUT \\
& - 1.4683 * PRICE\_L - 802.01 * PRICE\_K + 0.2743 * LNPRICE\_E \\
& + 0.0163 * TRPR\_L + 0.4902 * TRPR\_K + 0.0003 * TRPR\_E \\
& + 0.0111 * DISPR\_L - 0.1922 * DISPR\_K - 0.0001 * DISPR\_E \\
& + 2.4018 * REGNDUM1 + 1.9816 * REGNDUM2 + 2.0377 * REGNDUM3 \\
& + 0.8583 * REGNDUM4 + 0.2567 * YEARDUM1 + 0.2487 * YEARDUM2
\end{aligned}
$$

Appendix D 5

Total loss after separation:

表 15　纵向经济损失预测(3%)

	年份	纵向损失绝
		情景 1
总量	2006	2619.45
	2007	2750.43
	2008	2887.95
	2009	3032.35
	2010	3183.96

Appendix D 6

表 16　纵向经济损失预测(5%)

	年份	纵向损失绝
		情景 1
总量	2006	2670.32
	2007	2803.83
	2008	2944.03
	2009	3091.23
	2010	3245.79

Appendix D 7

Derivation of Ramsey Pricing Function:

其推导过程如下：

消费者剩余：$Z_i = \int_0^{q_i} p_i(q)dq - p_i(q_i)\cdot q_i$

生产者利润：$\Pi = \sum p_i(q_i)\cdot q_i - C(q_i)$，　$i = 1,2,3,\ldots,n$

规划问题：$\text{Max } S = \sum Z_i + \Pi$

$\text{St. } \sum p_i(q_i)\cdot q_i - C(q_i) \geq 0$

其中，$\sum p_i(q_i)\cdot q_i$ 表示企业收入，$C(q_i)$表示企业成本，则有

$$W = S + \lambda\left(\sum p_i(q_i)\cdot q_i - C(q_i)\right)$$

其中，λ 为拉格朗日乘子。对上式左右两边分别求一阶偏导，得，

$$\frac{\partial W}{\partial q_i} = (p_i - MC_i) + \lambda\left(\frac{\partial p_i}{\partial q_i}\cdot q_i + p_i - MC_i\right) = 0$$

$$\Rightarrow \quad (1+\lambda)(p_i - MC_i) = -\lambda\frac{\partial p_i}{\partial q_i}\cdot q_i \quad \Rightarrow \quad \frac{p_i - MC_i}{p_i} = \frac{\lambda}{1+\lambda}\cdot\frac{1}{\eta_i}$$

其中，p_i 是第 i 类用户的价格，MC_i 表示为第 i 类用户提供服务的边际成本，$\eta_i = -\frac{\partial p_i}{\partial q_i}\cdot\frac{p_i}{q_i}$ 为第 i 类用户的需求价格弹性。令 $R = \frac{\lambda}{1+\lambda}$ 表示拉姆齐数，则有

$$p_i = \frac{MC_i}{1 - \frac{R}{\eta_i}} = \kappa MC_i$$

Appendix D 8

Price Increase Derivation:

其推导过程如下：

消费者剩余：$Z_i = \int_0^{q_i} p_i(q)dq - p_i(q_i)\cdot q_i$

生产者利润：$\Pi = \sum p_i(q_i)\cdot q_i - C(q_i)$， $i=1,2,3,\ldots,n$

规划问题： $\text{Max } S = \sum Z_i + \Pi$

$\text{St. } \sum p_i(q_i)\cdot q_i - C(q_i) \ge 0$

其中，$\sum p_i(q_i)\cdot q_i$ 表示企业收入，$C(q_i)$表示企业成本，则有

$$W = S + \lambda\left(\sum p_i(q_i)\cdot q_i - C(q_i)\right)$$

其中，λ 为拉格朗日乘子。对上式左右两边分别求一阶偏导，得，

$$\frac{\partial W}{\partial q_i} = (p_i - MC_i) + \lambda\left(\frac{\partial p_i}{\partial q_i}\cdot q_i + p_i - MC_i\right) = 0$$

$$\Rightarrow \quad (1+\lambda)(p_i - MC_i) = -\lambda\frac{\partial p_i}{\partial q_i}\cdot q_i \quad \Rightarrow \quad \frac{p_i - MC_i}{p_i} = \frac{\lambda}{1+\lambda}\cdot\frac{1}{\eta_i}$$

其中，p_i 是第 i 类用户的价格，MC_i 表示为第 i 类用户提供服务的边际成本，

$\eta_i = -\frac{\partial p_i}{\partial q_i}\cdot\frac{p_i}{q_i}$为第 i 类用户的需求价格弹性。令 $R=\frac{\lambda}{1+\lambda}$表示拉姆齐数，则有

$$p_i = \frac{MC_i}{1-\frac{R}{\eta_i}} = \kappa MC_i$$

Appendix D 9